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An Integrated Shannon-PAF Method on Gray Numbers to Rank Technology Transfer Strategies

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Abstract: The selection of an appropriate technology transfer (TT) method is a complex multidimensional problem, which involves a multitude of situational qualitative and quantitative criteria. Despite multiple classifications and effective practices, expert opinion is still essential for every case. The complexity and dependence of TT method selection on human judgment have led to an increase in the application and integration of Multi-Criteria Group Decision-Making (MCGDM) methods, as well as fuzzy and gray systems theories, to address uncertainties related to data collection and selection of TT methods and criteria. The present study contributes to this trend by presenting a novel integrated Shannon-Projection Attribute Function (PAF) method, based on three-parameter interval gray numbers and describes its application in TT methods for the building industry. To calculate the weight of the assessment criteria, selected based on the literature review and Delphi panel, Shannon entropy can reduce uncertainties associated with the weighting criteria. Furthermore, three-parameter interval gray numbers can reduce uncertainties related to expert appraisal. In this study, we used the PAF method to rank TT methods. Also, we presented a brief analysis of the method application in the building industry. The results showed that reverse engineering and import of capital goods and machinery are the best TT methods, respectively.

Keywords: Shannon Entropy Method, Paf Method, Gray Numbers, Technology Transfer

EMJ Focus Areas: Technology Management, Project Management, Technology Selection

Technology management includes eight phases of creation, monitoring, assessment, transfer, acceptance, utilization, maturity, and decline (Bursic & Cleland, 1991). Technology transfer (TT) is a dynamic area of technology management, pursued at all firm, industry, and country levels (Bozeman et al., 2015). The selection of the right technology at the correct cost with the right set of attributes enables companies to reach and exceed their goals (Daim & Kocaoglu, 2008). Extensive technological changes in today's competitive world have encouraged organizations to develop and transfer technologies so that they do not lag behind other competitors. Considering the rapid pace of globalization and competitiveness of companies and countries in the global market, technological capabilities have been underlined as competitive advantages (Jones et al., 2001; Schepers & Wetzels, 2007).

Today, technology is no longer a license, a blueprint, a certificate, or a tangible resource to be imported, but is more of an intangible asset, similar to experiential and tacit technical knowledge that is path-dependent, cumulative, and difficult to imitate. Under a broad definition, if TT is assumed to be an uncertain, non-imitable, and path-dependent process, it can be conceived as an innovative development in which absorption capacity plays a crucial role (Saad, 2000). Appropriate TT has many advantages, such as increased income, innovation capabilities, competitive advantages, technical abilities, productivity, effectiveness, organizational learning, economic growth, and technological development of the industry (Abdul Wahab et al., 2010; Hsu, 2010; Schacht, 2012).

This paper focuses on ranking and selecting appropriate TT methods based on Multi-Criteria Group Decision-Making (MCGDM). Various TT methods and frameworks have been developed to ascribe appropriate TT methods to specific situations. Nevertheless, case-by-case judgment and group decision-making of experts still play essential roles in the strategic management of TT due to its complexities and uncertainties. Consequently, scholars integrated multi-criteria decision-making (MCDM) in the TT literature. Some researchers used the Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP), as two well-known ranking methods based on paired comparisons, to select and evaluate the critical success factors of TT (e.x., Attaran et al., 2014; Kumar et al., 2015a, 2015b; Lee et al., 2012; Lee et al., 2010a).

On the other hand, some scholars used a combination of MCDM methods to improve group decision-making in the evaluation, ranking, and selection of appropriate TT criteria, success factors, methods, and technology partners (donors or receivers). In this regard, Dinmohammadi and Shafiee (2017) proposed a decision model combining AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to determine the most suitable TT strategy for wind turbines. Nevertheless, these efforts have been infrequent and scarce, and most of the advanced MCDM methods do not address group decision-making in a TT context.

Insufficient analysis of combined group decision-making methods in the context of TT becomes much more important when one considers the increasing trend of fuzzy and gray systems incorporation into MCGDMs to address the vagueness and fuzziness of human judgment. Fuzzy and gray sets help convert the linguistic expressions of expert preferences into fuzzy numbers instead of crisp ones (e.g., TT strategy ranking and selection) (Albayrak & Erensal, 2009). While fuzzy and gray sets (and numbers) share multiple common features, they subtly diverge from each other concerning their intrinsic characteristics and goals. In brief, interval-valued gray sets are seen as an extension to fuzzy sets, which can more flexibly deal with fuzziness (Li et al., 2007). More specifically, gray sets can be used for both discrete and continuous data to overcome problems and preferences with higher uncertainty or less

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available information (Khuman et al., 2014). Practically, gray sets are preferred to fuzzy sets if there is a small number of samples or experts, limited experience, or less known preference membership functions.

A small number of studies have addressed fuzzy multi-criteria decision-making (FMCDM) for technology selection, while there have been no discussions about the selection of TT methods and strategies. For analysis and application of FMCDM in the strategic management of TT, methods proposed by Carlsson and Fullér (1996), Chang and Chen (1994), Hsu et al. (2015), and Lee et al. (2010b) have been used. Furthermore, gray multi-criteria decision-making (GMCDM) has been recently proposed in the TT literature (e.x., see Oztaysi, 2014; Tansel, 2012; Yurdakul, 2004). However, all of these studies aim at selecting the technology itself and fail to introduce appropriate TT strategies or methods. Also, no study has yet integrated the advantages of Projection Attribute Function (PAF) and Shannon entropy methods in this context.

The present study contributes to the available literature on ranking and selection of TT strategies by introducing a novel hybrid Shannon-PAF method over interval gray numbers to improve group decision-making. The proposed method aims to control uncertainties in different stages, which have been neglected in previous studies. The uncertainty usually occurs in three stages: data collection, data itself, and method of analysis and conclusion. In the proposed method, for collecting data, uncertainty was reduced by encouraging questions and answers between the researchers and experts and combining two methods of data collection, namely Delphi and the focal group. Gray numbers were also used to reduce data uncertainty. Also, a combination of decision-making methods and expert verification was used to control uncertainties attributed to the evaluation method. Overall, an evaluation and decision-making method may be associated with high uncertainty. However, a combination of different assessment methods can help researchers obtain more reliable results, which are closer to actual values.

The following section provides a review of the literature on TT strategies, evaluation criteria, applicable MCDM methods, and gray system theories and numbers. The methodology section presents the Shannon-PAF method. The findings section evaluates the application of the proposed method in the building industry. The next section describes the implications for engineering managers and discusses the implementation of the proposed model by engineers and managers to obtain better TT results in organizations. The final section presents the conclusions and some recommendations for future studies.

Literature Review

The following subsections describe the background of TT strategies, assessment criteria of TT strategies, empirical studies on the application of group decision-making methods in the TT literature, and concepts of gray and fuzzy numbers.

TT Strategies

It is necessary to be familiar with the variety of TT methods and processes developed so far. At the company level, the selection of the right technology from the right source through an appropriate TT method is a strategic decision for transferring technological knowledge (Kumar et al., 2015b; Lee & Song, 2007; Torkkeli & Tuominen, 2002). Therefore, the success of TT is not only dependent on the selection of technology, but is also related to the method of transfer and donor and receiver capabilities. The selection of an appropriate TT method is even more important when the high failure rate of TT projects is taken into account (see Guan et al., 2006).

There are various TT methods for different types of technology and transfer conditions, which yield multiple options. Transfer methods may require the minimum engagement of the recipient by relying mostly on foreign resources, while they require maximum involvement in cases leading to technology localization (Lavoie, 2019). There are various classifications suggested for TT methods. For instance, in human exchange and employment, the recipient employs professionals under specific conditions or utilizes the professional services of other organizations (Chiesa & Manzini, 1998). By acquisition and equity investment, the recipient purchases the company owning the intended technology or a share of it instead of a direct TT (Chiesa & Manzini, 1998).

Equity investment in other companies, which is of different forms, provides access to technology. A recipient may invest in a donor firm, or vice versa, to get access to a technology (Lee, 2002). Training and education is another TT method, which involves the transfer of workforce abroad for education and training purposes. This method can be classified into two modules: training and education (Radosevic, 1999). On the other hand, in reverse engineering, the technology recipient acquires a technology by simulation, code-breaking, remanufacturing, and reassembling products (Khalil, 2000). This method is also called “imitation” or “replication” (Lee, 2002).

Foreign Direct Investment (FDI) is also a common method of TT, where foreigners play an active role and apply the information without considerable time loss. In addition to technology, management skills, and market communication are imported into the receiving country alongside direct investment; this method requires basic capabilities (Kondo, 2005). In turnkey contracts, the technology donor controls all stages of design, installation, setup, and initial operation for the purchased technology. In particular cases, a turnkey contract incorporates post-installation training and support (Khalil, 2000; Williams, 2019).

In joint ventures, two or more companies share their technological capabilities, knowledge, and resources for the development of a specific technology, where a third company (with limited life) is established, with all parties sharing the profits and losses (Chiesa & Manzini, 1998; Khalil, 2000; Roberts & Berry, 1984). Licensing (see Khalil, 2000; Radosevic, 1999), import of capital goods and machinery (see Acharya & Keller, 2009; Henry et al., 2009), and buyback contracts (see Mabadi, 2007; Van Groenendaal & Mazraati, 2006) are three other TT strategies. In the alliance mode of TT, two companies share their technological abilities to acquire a new technology (Chiesa & Manzini, 1998). This transfer method resembles a joint venture with the difference that no shares are exchanged and that it is short-termed (Roberts & Berry, 1984).

Outsourcing and contract-out research and development (R&D) are two other TT strategies. In contract-out R&D, an organization defines a part of its R&D activities as a project and outsources it with a contract (Khalil, 2000). In outsourcing, transfer of technology or technical knowledge of manufacturing may occur as a result of the delivery of outsourced products manufactured by a contractor, which is often accompanied by quality control or even control of the manufacturing process by the client (Chiesa & Manzini, 1998). Complete transfer of technology sometimes requires a combination of several TT methods (Razgaitis, 1999). Some evaluation criteria must be developed for TT strategies to select the most appropriate method. The next section provides a background on these evaluation criteria.

Evaluation Criteria for TT Strategies

In this section, influential factors of TT were investigated by reviewing the literature of TT methods and benchmarking previous studies (see Aloini et al., 2018; Abdullah & Rahman, 2017; Montazeri & Najjartabar-Bisheh, 2017; Akhundzadeh & Shirazi, 2017; Horner et al., 2019; Oztaysi et al., 2017; Kharat et al., 2016; Lu et al., 2016; Gebrekidan et al., 2019; Ren & Lützen, 2015; Jenab et al., 2015; Asad et al., 2015; Jafarnezhad et al., 2013; Shouwu et al., 2016; Chehrehpak et al., 2012; Kumar et al., 2015a; Lee et al., 2012; Moradian et al., 2010; Bar-Zakay, 1971; Battistella et al., 2016; Behrman & Wallender, 1976; Bozeman, 2000; Bozeman et al., 2015; Chantramonklasri, 1990; Chatterji, 2016; Chiesa & Manzini, 1998; Dahlman & Westphal, 1981; Durrani et al., 1998; Jagoda, 2007; Keller & Chinta, 1990; Khalil, 2000; Lee, 2002; Lee et al., 1988; Ramanathan, 2008; Razgaitis, 1999; Reddy & Zhao, 1990; Roberts & Berry, 1984; Schlie et al., 1987; Maludin et al., 2019; Nosal Hoy et al., 2019). There are various criteria for the evaluation, ranking, and selection of appropriate TT and TT methods. Exhibit 1 presents the most common criteria. Some of these criteria are orthonormal based on the supported definitions and influence some others.

Decision-Making Methods in TT

In the past two decades, researches have studied the utilization of (group) decision-making methods for TT and technology selection. The literature review shows that decision-making methods, such as multi-attribute or multi-criteria decision-making (MADM or MCDM), ELECTRE, TOPSIS, ANP, Decision Making Trial and Evaluation Laboratory (DEMATEL), data envelopment analysis (DEA), and AHP, have been used in studying and ranking TT. Also, a limited number of studies are concerned with decision-making for TT methods (strategies). Exhibit 2 describes some studies about decision-making methods in the field of TT for both technology selection and TT method selection.

Gray Numbers

The integration of fuzzy system theories, sets, and numbers has increased in MCDMs, mostly to deal with fuzziness, uncertainties, and vagueness of human preferences and judgments (Lee et al., 2012). More recently, significant attention has been paid to the infusion of gray numbers and sets into the MCDM literature because of their prominent role in indeterminate decision-making, where the decision matrix can not be represented by determinate numbers (Bu & Zhang, 2001; Liu & Forrest, 2010; Luo, 2005; Luo & Liu, 2005). Exhibit 3 presents the concept of gray systems schematically.

If the black color represents information totally unknown, and white represents completely known information, gray indicates information that is partially unknown and partially known. A system is called gray when it includes gray information (Liu et al., 2013; Yu et al., 2018). For military, engineering, monetary, and economic purposes, attribute values are usually represented as gray numbers (Liu et al., 2018).

Basic Definitions and Concepts of Three-parameter Interval Gray Numbers

$a(\otimes) \in [\underline{a},\ \bar{a}]$ represents an interval gray number (Dang, 2009; Liu et al., 2013). A three-parameter gray number, $a(\otimes)$, can be shown as $a(\otimes) \in [\underline{a},\ \tilde{a},\ \bar{a}]$, where $\underline{a}$ denotes low boundary, $\tilde{a}$ denotes the gravity center (most probable number), and $\bar{a}$ indicates high boundary. In cases where the gravity center is not known, a three-parameter gray number is converted into a standard gray number (Liu et al., 2018). Evaluation of alternatives with three-parameter interval gray numbers has distinct advantages, as the value range of interval gray numbers is guaranteed, and the poor information of gray numbers can also be compensated for by emphasizing the highest possible point. Therefore, the results of methods with three-parameter interval gray numbers are more satisfactory in engineering (Dang, 2009).

Three-parameter interval gray numbers operate similarly to interval gray numbers. If, $b(\otimes) \in \left[\underline{b}, \tilde{b},\ \bar{b}\right]$ is another three-parameter interval gray number, addition and division operations will be as follows:

$$a(\otimes) + b(\otimes) \in \left[\underline{a} + \underline{b},\ \tilde{a} + \tilde{b},\ \bar{a} + \bar{b}\right], \tag{1}$$

$$a(\otimes)/b(\otimes) \in \Big[\min\{\underline{a}/\underline{b},\ \underline{a}/\bar{b},\ \bar{a}/\underline{b},\ \bar{a}/\bar{b}\},\ \tilde{a}/\tilde{b},\ \max\{\underline{a}/\underline{b},\ \underline{a}/\bar{b},\ \bar{a}/\underline{b},\ \bar{a}/\bar{b}\}\Big] \tag{2}$$

Based on the basic concepts of mathematical sets, only the definition of two basic mathematical operations is sufficient, and the other two basic mathematical operations can be defined based on these two basic operations. For instance, for the division operation, the first number is multiplied by the inverse of the second number (Herstein, 1999).

The decision-making based on three-parameter interval gray numbers can be defined as follows (Dang, 2009):

If the alternative set is defined as $A = \{A_1, A_2,\ \ldots\ A_n\}$, the criteria (attributes) set is defined as $S = \{S_1,\ S_2,\ \ldots\ S_m\}$, the evaluation vector for decision alternatives can be defined as:

$$x_i(\otimes) = \ (x_{i1}(\otimes),\ x_{i2}(\otimes),\ \ldots\ ,\ x_{im}(\otimes)) \tag{3}$$

where $x_{ij}(\otimes) \in \left[\underline{x}_{ij},\ \tilde{x}_{ij},\ \bar{x}_{ij}\right]$ $\left(0 \le \underline{x}_{ij} \le \tilde{x}_{ij} \le \bar{x}_{ij},\ i = 1,\ 2,\ \ldots,\ n;\ j = 1,\ 2,\ \ldots\ ,m\right)$, as a three-parameter interval gray number belonging to $[0, 1]$, represents the evaluation information of alternative A_i with respect to the criterion S_j. The goal is to reach a reasonable ranking of alternatives by a comprehensive integration of the given evaluation information. For the sake of simplicity, $\underline{x}_j^+ = \max\limits_{1\le i\le n}\left\{\underline{x}_{ij}\right\}$, $\tilde{x}_j^+ = \max\limits_{1\le i\le n}\{\tilde{x}_{ij}\}$, $\bar{x}_j^+ = \max\limits_{1\le i\le n}\{\bar{x}_{ij}\}$, $\underline{x}_j^- = \min\limits_{1\le i\le n}\left\{\underline{x}_{ij}\right\}$, $\tilde{x}_j^- = \min\limits_{1\le i\le n}\{\tilde{x}_{ij}\}$, and $\bar{x}_j^- = \min\limits_{1\le i\le n}\{\bar{x}_{ij}\}$, where $(i = 1,\ 2,\ \ldots\ ,\ n;\ j = 1, 2,\ \ldots\ , m)$ are defined. The following non-negative m dimension three-parameter interval gray number vectors are called ideal optimal alternative (positive ideal) evaluation vector and critical alternative (negative ideal) evaluation vector:

Exhibit 1. Criteria for the Selection of Technology Transfer (TT) Methods Based on the Literature Review and Open Interviews

No.	Criteria	Definition
1	Quality of contracting and implementation	In this criterion, various factors involved in contract execution, such as terms and conditions, limiting terms by the technology provider, and contract enforcement requirements, are taken into account, and various TT methods are ranked accordingly.
2	Research budget	Available research budgets should be considered to select the appropriate TT method. In the absence of adequate research budgets, TT strategies requiring high research budgets are not recommended.
3	Professional human resources	The technology receiver needs skilled human resources to fully utilize imported technology. Also, the availability of specialists for any particular TT method must be carefully considered.
4	Technology adaptability	The more TT strategy can adapt transferred technology to the available technologies of the recipient and other emerging technologies, the more it is preferred.
5	Familiarity with the market and technology	Market and technology criterion status is divided into basic, new and known, and new and unknown types. The selected TT method depends on the market status.
6	Nature of technology	This criterion is measured by factors, such as technology life cycle, the competitiveness of technology, ease of understanding the technology, technology complexity, level of tacit knowledge of technology, and so on.
7	Characteristics of the donor organization	This criterion includes cultural differences, areas of activity, power of the technology provider, ability to protect technology, speed of technology acquisition, intellectual property, desire and ability of the recipient to meet the requirements of the technology provider, ability of the provider to control the use of technology by the receiver, and so on.
8	Policies of donor organization	This criterion is measured based on the following factors: monitoring of technology application by the recipient after transfer; application of monopoly restrictions in contracts by the technology provider for the supply of raw materials; support and sale of products; restrictions in technology modifications; and development and dissemination of technology after the maturity stage of transferred technology.
9	Policies of the recipient organization	This criterion includes the required level of investment, the need for rapid access to technology, the ability to maintain technology after TT, the need for technology ownership in the firm, and so on.
10	The appropriate type of partnership between donor and recipient	This criterion includes the purpose of the partnership, the ability to define partnership terms, communication ways of companies, the capability of dividing stocks, the long-term horizon of cooperation, contract flexibility, and so on.
11	Type and attractiveness of the technology	This criterion includes the characteristics, effects, and role of technology in the recipient's organization. Based on these factors, the recipient's interest in different TT models will vary.
12	Technology life cycle	Each stage of the technology life cycle has specific characteristics that distinguish it from other stages. The way of handling technology and the best TT method differ in different life cycles of technology.
13	Technology change rate	The pace of technology change is important in choosing the TT method. If this change is negative or zero, the tendency toward outsourcing methods will be greater. On the other hand, the greater the rate of change is, the greater the tendency toward endogenous TT methods will be.
14	Availability of diverse supply resources	One or a few organizations sometimes monopolize technology. Political and economic sanctions also make some of the resources unavailable, which may can affect the selection of TT methods.
15	Complexity degree of technology	More sophisticated technologies require closer collaboration between the technology provider and the receiver. The more complex a technology is, the more difficult it will be to absorb and localize it; also, it requires more competencies.
16	Environmental factors	The specific economic culture of the receiver country, political and economic sanctions, and other factors make some of the technology providers unavailable to provide technology easily.

Exhibit 1. Criteria for the Selection of Technology Transfer (TT) Methods Based on the Literature Review and Open Interviews *(continued)*

No.	Criteria	Definition
17	Legal infrastructure	The more governmental, legal, and political support is provided, the more easily and thoroughly the process of TT will be accomplished. Different TT methods require different stages of governmental, legal, and political support.
18	Competitive (strategic) effect of technology	Since knowledge and technology bring competitive advantages to companies, under similar conditions, a TT method, which gives the organization more competitive advantages, is preferred over other TT methods.
19	Position of technology in the organization	The characteristics, effects, and roles of technology in the firm determine its position and attractiveness. The position and attractiveness of technology are important in the selection of the TT method.
20	Relative organizational capability for a technology (relative to competitors and the ideal state)	As the firm's ability to develop technology increases, the tendency toward its endogenous development becomes more and more likely to succeed.
21	The time needed to acquire a technology (necessity of rapid achievement of technology)	Among various TT methods, the receiver seeks a method in which transfer, localization, and development take place in the shortest possible time. Different TT methods are not similar regarding the transfer time.
22	The necessity for the acquisition of technology	TT method selection depends on its strategic importance for the company.
23	Effect of technology on other industries	As the national impact of technology on other industries increases, its endogenous development becomes more justified because the availability of internal knowledge allows its application in other industries in a way the country needs.
24	Growth of technology attractiveness	In the selection of an appropriate TT method, the attractiveness or importance of technology is considered a criterion in the short-, medium-, and long-terms.
25	Cost of technology development	If the goal is to transfer technology rather than develop it through organizational research, it is important to minimize the cost of TT; therefore, and a method of transfer that involves the lowest possible cost after transfer must be adopted.
26	Maximum of technology absorption	To increase technology absorption, a method of TT which ensures more technology adaptability to the firm, is preferred.
27	Maximum of market access	The recipient should try to select a TT method that will guarantee maximum market access in the future.
28	Maximum of alignment with technological changes	While choosing a TT method, maximum alignment with technological changes is essential. For example, if technology is in the maturity stage and its development is rapid, internal development and even TT will not be very effective, and it is recommended to import he capital goods and machinery.
29	Organizational culture (innovative, supportive, bureaucratic, effective)	While choosing a TT method, the culture of the recipient firm and its cultural distance from the provider of the technology should be carefully considered. The importance of organizational culture varies in different TT methods.
30	Channels of technology diffusion (formal and informal)	Communication channels, including individuals and companies, play a facilitating role between the recipient and the technology provider. They accelerate the negotiation process between the two parties. The need for communication channels varies in different TT methods.
31	Balance mechanism (internal and external organization)	When choosing the best TT method, in-house R&D resources must be utilized to achieve the best results. Different TT strategies require different amounts of available in-house R&D.
32	R&D resources (assets and abilities)	When choosing the best TT method, the available R&D resources in the company are important. These resources can be in the form of assets or knowledge capabilities. Different TT methods require different R&D capabilities.
33	Infrastructural factors (physical, economic, social, technological, etc.)	This criterion considers factors, such as level of information technology, level of R&D, availability of local contractors, training, standards, level of management, and so on.
34	Lost opportunity cost	Failure of the TT process imposes costs on the company. While choosing a TT method, close attention must be paid to this criterion to minimize the probable cost.
35	Government policies	The extent of governmental support policies, as well as regulations supporting TT, is important in choosing a TT method.
36	Organization size	When choosing a TT method, one must consider the characteristics of the organization. One of the most important characteristics of the organization is its size.

Exhibit 1. Criteria for the Selection of Technology Transfer (TT) Methods Based on the Literature Review and Open Interviews *(continued)*

No.	Criteria	Definition
37	The mind-set of technology donor and recipient	The selection of a TT method is largely dependent on the similar mind-sets of the technology provider and the recipient regarding the TT process and its goals. TT methods that aim at acquiring and localizing technology and state-of-the-art knowledge require very close mind-sets of the recipient and donor of technology.
38	Educational background of technology donor and recipient	When choosing a TT method, the provider and recipient's educational background and any possible gaps are important. TT methods that aim at acquiring and localizing technology and state-of-the-art knowledge need similar educational backgrounds.
39	Technology maintenance costs	The overhead and downstream costs, including maintenance costs, are important in choosing a technology and its transfer method.
40	Managerial capabilities	Different TT methods require different managerial experiences. Therefore, to select an appropriate TT method, work experience and managerial records of the provider and recipient must be taken into consideration.
41	Indigenous and environmental (restrictive) factors	Restrictive factors, such as the country's specific economic culture, political sanctions, and environmental laws, are effective in choosing a TT method.
42	The potential effect of technology on the industry	Since full mastery of technological knowledge allows its application in other industries, the endogenous development of the technology becomes more justified as its national impact increases. Obviously, in this situation, TT methods that assure mastery of tacit and technical knowledge are prioritized.
43	Macro, and micro- environment of technology recipient	A macro-environment that encompasses both the technology provider and the recipient involves political relations between the two countries, governmental obligations, exchange rates, investment climate, trade negotiations, trade balances, and symmetric technology. Likewise, the micro-environment of each TT actor has an impact on its characteristics and influences the TT process.
44	Regional and global policies	Global policies, as well as regional policies, including sanctions and tariffs, restrict the selection of TT methods.

$$x^{+}(\otimes) = \left(x_1^{+}(\otimes), x_2^{+}(\otimes), \ \ldots \ , x_m^{+}(\otimes)\right), \ \ x^{-}(\otimes) = \left(x_1^{-}(\otimes), x_2^{-}(\otimes), \ \ldots \ , x_m^{-}(\otimes)\right) \quad (4)$$

Where:

$x^{+}(\otimes) \in \left[\underline{x}_j^{+}, \ \tilde{x}_j^{+}, \ \bar{x}_j^{+}\right], \ \ x^{-}(\otimes) \in \left[\underline{x}_j^{-}, \ \tilde{x}_j^{-}, \ \bar{x}_j^{-}\right] \quad (j = 1, 2, \ \ldots \ , m).$

Gap Analysis

Regarding TT methods, limited studies have proposed an easy step-by-step solution for engineers and managers to help them rank different TT models in uncertain conditions. To reduce uncertainty, this study contributes to the current literature of TT method selection in the following ways:

- The literature review indicated the evaluation criteria, and complementary criteria were proposed.
- The proposed model could be used to find reliable answers in uncertain situations.
- This was the first study to combine Shannon and PAF methods with the application of gray numbers to propose a new integrated model for ranking TT strategies.
- The proposed model benefited from both qualitative and quantitative approaches.
- The findings might be applied in actual case studies of different industries, including the building industry.

Shannon-PAF Methodology

This is a quantitative and developmental study. First, based on the literature review and open interviews, well-known TT methods (strategies) and their classifications were identified, and evaluation criteria for their ranking and selecting were determined. The focal group approach can be used as an early auxiliary stage in quantitative studies (Khan et al., 1991). To omit less important criteria or items, experts' opinions can be integrated in sessions of the focal group (Gatti, 2005; Batchelor & Briffa, 2011; De FA Obregon et al., 2016). Also, Delphi method is suitable for collecting and refining experts' opinions and judgments through repeated surveys when there is a lack of empirical data (Cottam et al., 2004; Edwards et al., 2011; Eycott et al., 2011; Ruivo et al., 2019). Then, In the next step, by the formation of a focal group and using a Delphi panel to evaluate the criteria and TT models, six criteria were identified for ranking five TT methods in the building industry, and their definitions were finalized. In the focal group, experts were asked to express their opinion based on a nine-point scale, where one represented "not important", and nine represented "absolutely essential". Based on previous researches, including studies conducted by Cottam et al. (2004) and Von der Gracht (2008), to analyze the Delphi questionnaires, the Average Percentage of Majority Opinions (APMO) was employed to produce a cutoff rate and decide whether consensus could be reached. Since screening and finalization of TT methods and evaluation criteria, obtained from the literature review and open interviews, are not the primary objectives of this study, comprehensive explanations about the focal group, Delphi

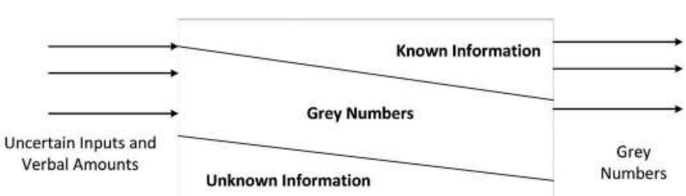
Exhibit 2. Research Background

Researcher	Research
Solgi et al. (2019)	A hybrid hierarchical soft computing approach for the technology selection problem in the brick industry considering environmental competencies: A case study
Wang et al. (2019)	Selecting sustainable energy conversion technologies for agricultural residues: A fuzzy AHP-VIKOR based prioritization from the life cycle perspective
Aloini et al. (2018)	Technology assessment with IF-TOPSIS: An application in the advanced underwater system sector
Yang et al. (2018)	Using multi-criteria analysis to prioritize renewable energy home heating technologies
Sahin and Yip (2017)	Shipping technology selection for dynamic capability based on improved Gaussian fuzzy AHP model
Oztaysi et al. (2017)	Multi-criteria alternative-fuel technology selection using interval-valued intuitionistic fuzzy sets
Abdullah and Rahman (2017)	Analytic network process for developing relative weight of wastewater treatment technology selection
Montazeri and Najjartabar-Bisheh (2017)	Optimizing technology selection for power smart grid systems: A case study of Iran power distribution industry (IPDI)
Chang et al. (2016)	Study to evaluate the achievements of R&D of SME's using the AHP: Transfer of technology development project
Wan et al. (2016)	A novel group decision making method with intuitionistic fuzzy preference relations for RFID technology selection
Lu et al. (2016)	Health-care waste treatment technology selection using the interval 2-tuple induced TOPSIS method
Robert et al. (2015)	Technology selection and sitting of a biogas plant for OFMSW via multi-criteria decision analysis
Ren and Lützen (2015)	Fuzzy multi-criteria decision-making method for technology selection for emissions reduction from shipping under uncertainties
Kahrizeh and Ghaderi (2014)	Evaluation and scrutiny of the appropriate method of technology transfer using DEA method
Eren et al. (2015)	Selection of technology transfer method for defense industry using AHP
Hsu et al. (2015)	Toward successful commercialization of university technology: Performance drivers of university technology transfer in Taiwan using ISM and ANP
Aliakbari Nouri et al. (2015)	A hybrid MCDM approach Based on fuzzy ANP and fuzzy TOPSIS for technology selection
Kumar et al. (2015b)	Identification and evaluation of critical factors to technology transfer using AHP approach
Van de Kaa et al. (2014)	A photovoltaic technology was selected using AHP and logarithmic fuzzy preference programming
Troldborg et al. (2014)	The paper assessed the technologies available for the sustainability and preservation of renewable energies. It has used Monte-Carlo simulation and multi-criteria decision-making under uncertainty.
Oztaysi (2014)	A decision model was used for information technology selection using AHP integrated TOPSIS-Gray method.
Jafarnezhad et al. (2013)	The priority of technology transfer methods in oil drilling Industry by using ANP
Streimikiene et al. (2013)	Road transport technologies have been investigated and compared using the multi-criteria decision making (MCDM) method of interval TOPSIS.
Evans et al. (2013)	A fuzzy-decision-tree approach was developed for manufacturing technology selection exploiting data mining on experience-based information.
Stein (2013)	A comprehensive multi-criteria model was developed to rank electric energy production technologies using AHP.
Chehrehpak et al. (2012)	Selecting of optimal methods for the technology transfer by using AHP
Tavana et al. (2013a)	A hybrid fuzzy group decision support framework was developed for advanced-technology prioritization at NASA using ANP and fuzzy TOPSIS methods.
Tavana et al. (2013b)	A fuzzy group data envelopment analysis model was proposed for high-technology project selection, which was implemented at NASA as a case-study.
Kalbar et al. (2012a)	High-technologies for wastewater treatment were assessed using multiple-attribute decision-making (MADM) and then a new model was proposed.
Kalbar et al. (2012b)	The selection of an appropriate wastewater treatment technology was intended, in which six scenarios were developed. Then the best technology was selected using a scenario-based multiple-attribute decision-making approach and with the aid of the TOPSIS method.
Shen et al. (2011)	Combining the techniques of DEMATEL, fuzzy DELPHI, and ANP, a novel MCDM model was developed for the selection of organic light-emitting diode technologies.
Kabaranzad Ghadim and Sohrabi (2011)	The paper attempted to recognize factors effective in the evaluation and selection of optimal technology transfer methods in the Tehran Gas Organization (Iran).

Exhibit 2. Research Background *(continued)*

Researcher	Research
Taghavifard et al. (2011)	A hierarchical fuzzy TOPSIS model was used for the evaluation of technology transfer in the medical industry and equipment.
Moradian et al. (2010)	Prioritization of technology transfer methods to downstream petrochemical industries in developing countries.
Lee et al. (2010b)	An evaluation framework for technology transfer of new equipment in the high technology industry
Albayrak and Erensal (2009)	Fuzzy linear programming technique was used for multi-attribute group decision making with fuzzy decision variables, to leverage technological knowledge transfer.
Chuu (2009)	A group decision-making model was developed using a fuzzy multiple-attribute analysis for the evaluation of advanced manufacturing technology.
Saen (2006)	A decision model was developed for selecting technology suppliers in the presence of nondiscretionary factors using DEA.
Prabhakaran et al. (2006)	They selected an optimum technology for composite product systems using a MADM approach, specifically TOPSIS.
Hajeeh and Al-Othman (2005)	It has applied AHP in the selection of desalination plants.
Malladi and Min (2005)	It showed how decision support models could be utilized for the selection of internet access technologies in rural communities.
Yurdakul (2004)	A combination of the AHP method and goal programming method was used to select computer-integrated manufacturing technologies. Tansel (2012) has also used the TOPSIS decision-making method combined with gray system theory to solve a problem in the same context.
Azar and Tabatabaie (2003)	Designing a decision-making model for selecting technology transfer projects
Talluri and Yoon (2000)	A cone-ratio DEA approach was developed based on DEA for the problem of the process of technology selection within the context of manufacturing technologies.
Baker and Talluri (1997)	A method was proposed for ranking of technologies using DEA, addressing the shortcomings of Khouja's (1995) paper, which claimed a more robust solution.
Khouja (1995)	It used a two-stage process for solving the technology selection problem. In the first stage, technologies that best improve collaboration between employees were selected. Then in the second stage, these selected technologies are ranked using a MADM approach.
Chang and Chen (1994)	A fuzzy multi-criteria decision-making method for technology transfer strategy selection in biotechnology.

Exhibit 3. A Gray System (Li et al., 2007)



method, and their application are presented in Appendix A and Appendix B.

Afterward, the novel Shannon-PAF method was applied based on the expert judgment in the building industry. For this purpose, the experts first evaluated each TT method based on the criteria. Then, linguistic expressions provided by the experts were converted into three-parameter gray numbers and averaged. The weights of the criteria were calculated using the Shannon entropy method, and in the final stage, TT methods were ranked by applying the PAF method. Thirty-four experts were selected by the snowball sampling method and recruited in the focal group and Delphi panel. The experts also contributed to the Shannon and PAF methods for related evaluations and judgments. Exhibit 4 presents the demographic characteristics of the sampled expert population. Exhibit 5 presents the conceptual map of the research path.

Exhibit 4. Demographic Characteristics of the Sampled Experts

Gender		Education			Experience of Technology Transfer (TT) in the Building Industry		
Male	Female	Bachelor	Master	PhD	< 5 years	5-15 years	>15 years
34	0	8	16	10	6	12	16
100%	0%	23,5%	47.1%	29.4%	17.6%	35.3%	47.1%

As discussed earlier, the value and importance of each TT method were evaluated against the evaluation criteria. Values corresponding to the linguistic variables were translated into three-parameter gray numbers and then averaged. Exhibit 6 presents the standard linguistic variables used for the evaluation of TT methods and their three-parameter gray numbers.

The criteria were weighted based on the Shannon entropy method. Entropy is a concept in information theory, which represents the uncertainty of a message. Uncertainty can be expressed as below (Ringuest, 2012; Shannon, 2001; Shannon & Weaver, 1949):

$$E \approx S\{P_1, P_2, \ \ldots \ , P_n\} = -k\sum_{i=1}^{m}[P_i Ln(P_i)] \tag{5}$$

where k is a positive constant, E represents uncertainty, and S is a set of messages displayed as $(P_1, P_2, \ldots, P_n)$.

The weighting algorithm of Shannon entropy is used in MCDM theory, based on the following steps (Hwang & Masud, 2012; Kamfiroozi et al., 2012):

The decision matrix (D) of n alternatives and m criteria (attributes) is as follows:

$$D = \begin{bmatrix} u_{11} & u_{12} \cdots & u_{1m} \\ u_{21} & \ddots & \vdots \\ \vdots & & \\ u_{n1} & \cdots & u_{nm} \end{bmatrix}$$

Step 1: The decision matrix is descaled to prepare it for further comparisons. The outcomes of criterion j can be defined as follows:

$$x_{ij} = \frac{u_{ij}}{\sum_{i=1}^{n} u_{ij}}, \ i = 1, \ 2, \ \ldots \ , n; \ j = 1, \ 2, \ \ldots \ , m) \tag{6}$$

Step 2: Entropy of the set of outcomes of criterion j, indicating its uncertainty, is computed as follows:

$$E_j = -k\sum_{i=1}^{n}[x_{ij} Ln(x_{ij})] \tag{7}$$

where k is a constant value $k = \frac{1}{\mathrm{Ln}(n)}$, which guarantees $0 \leq E_j \leq 1$, and n denotes the number of rows in the decision matrix.

Step 3: The degree of diversification of information provided by the outcomes of criterion j, indicating its certainty, is defined as follows:

$$d_j = 1 - E_j \tag{8}$$

Step 4: The weight of each criterion is computed as follows:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{9}$$

Step 5: If the decision-maker assigns external subjective weights to the criteria (λ_j), the normalized weights can be calculated as follows:

$$w_j' = \frac{\lambda_j w_j}{\sum_{j=1}^{m} \lambda_j w_j} \tag{10}$$

TT methods can be ranked by the PAF method. This method, with three-parameter interval gray numbers, was first introduced by Dang (2009) and involved a procedure as described below:

Based on Eq. (3), for the sake of simplicity, the normalized evaluation vector of decision alternatives (A_i) can be represented as a normalized decision-making matrix:

$$x_i(\otimes) = \ (x_{ijk})_{3\times m} = \begin{bmatrix} x_{i11} & x_{i12} & \cdots & x_{i1m} \\ x_{i21} & x_{i22} & \cdots & x_{im} \\ x_{i31} & x_{i32} & \cdots & x_{i3m} \end{bmatrix}, \quad (i = 1, \ 2, \ \ldots \ , n) \tag{11}$$

Exhibit 5. Schematic Presentation of the Study Methodology

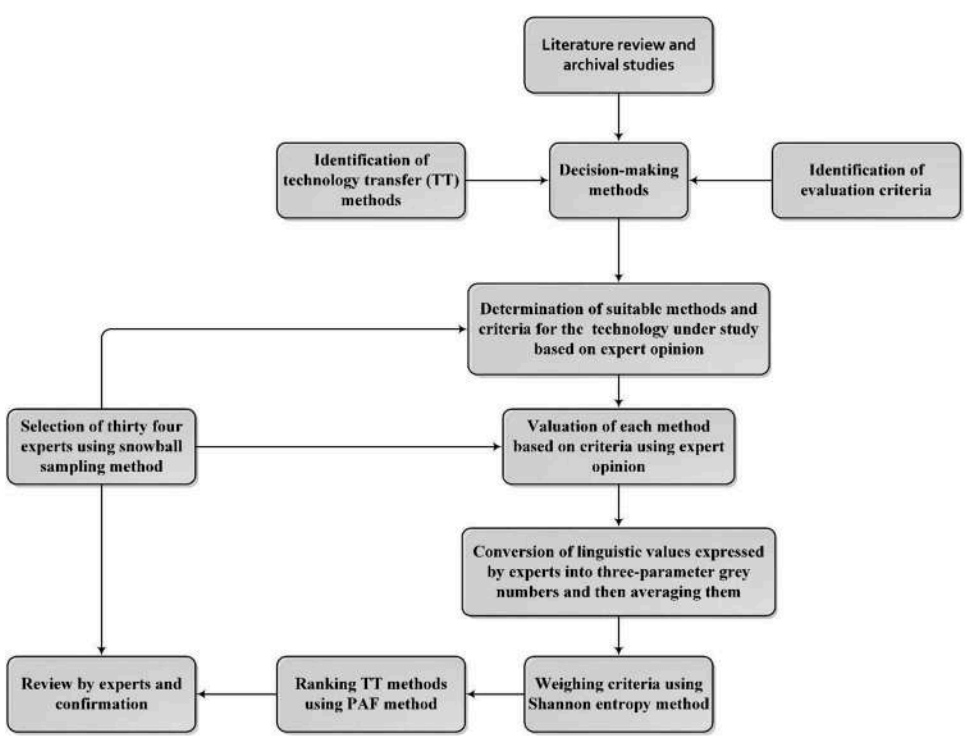


Exhibit 6. Variables and Their Corresponding Three-parameter Interval Grey Numbers (Bai et al., 2019; Kamfiroozi et al., 2012)

Five-Point Scale	Linguistic Variable	Three-Parameter Gray Number
1	Very low	(0, 0.1, 0.2)
2	Low	(0.2, 0.3, 0.4)
3	Medium	(0.4, 0.5, 0.6)
4	High	(0.6, 0.7, 0.8)
5	Very High	(0.8, 0.9, 1.0)

where $x_{i1j} = \underline{x}_{ij}, x_{i2j} = \tilde{x}_{ij}, x_{i3j} = \bar{x}_{ij}, (i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m)$.

Similarly, in Eq. (4), the ideal optimal alternative evaluation vector and critical alternative evaluation vector can be rewritten as the following decision-making matrices:

$$x^{+}(\otimes) = \left(x_{kj}^{+}\right)_{3\times m} = \begin{bmatrix} x_{11}^{+} & x_{12}^{+} & \cdots & x_{1m}^{+} \\ x_{21}^{+} & x_{22}^{+} & \cdots & x_{2m}^{+} \\ x_{31}^{+} & x_{32}^{+} & \cdots & x_{3m}^{+} \end{bmatrix}$$

$$x^{-}(\otimes) = \left(x_{kj}^{-}\right)_{3\times m} = \begin{bmatrix} x_{11}^{-} & x_{12}^{-} & \cdots & x_{1m}^{-} \\ x_{21}^{-} & x_{22}^{-} & \cdots & x_{2m}^{-} \\ x_{31}^{-} & x_{32}^{-} & \cdots & x_{3m}^{-} \end{bmatrix} \tag{12}$$

where the symbols represent $x_{1j}^{+} = \underline{x}_j^{+},\ x_{2j}^{+} = \tilde{x}_j^{+},\ x_{3j}^{+} = \bar{x}_j^{+}$, $x_{1j}^{-} = \underline{x}_j^{-},\ x_{2j}^{-} = \tilde{x}_j^{-},\ x_{3j}^{-} = \bar{x}_j^{-}$, and $j = 1,\ 2,\ \ldots,m$.

The weight vector of a criterion is assumed to be $\omega_j (j = 1, 2, \cdots, m)$. According to the definition of three-parameter interval gray numbers, the vector $e = (1-\mu, 1, \mu, \omega_1, \omega_2, \cdots, \omega_m)$ can be considered as the projection direction ($\mu \in [0, 1]$). For each i = 1, 2, …, n, the following equations are defined:

$$Z(i)_1^{-} = \sum_{j=1}^{m} \omega_j \left(x_{i1j} - x_{1j}^{-}\right)^2, Z(i)_2^{-} = \sum_{j=1}^{m} \omega_j \left(x_{i2j} - x_{2j}^{-}\right)^2,$$
$$Z(i)_3^{-} = \sum_{j=1}^{m} \omega_j \left(x_{i3j} - x_{3j}^{-}\right)^2$$

$$Z(i)_1^{+} = \sum_{j=1}^{m} \omega_j \left(x_{i1j} - x_{1j}^{+}\right)^2, Z(i)_2^{+} = \sum_{j=1}^{m} \omega_j \left(x_{i2j} - x_{2j}^{+}\right)^2,$$
$$Z(i)_3^{+} = \sum_{j=1}^{m} \omega_j \left(x_{i3j} - x_{3j}^{+}\right)^2 \tag{13}$$

Assume that the standard evaluation vector for any alternative, ideal optimal alternative, and critical alternative are defined by Eqs. (11) and (12). $Z(i)_k^{-}, Z(i)_k^{+} (i = 1, 2, \cdots, n; k = 1, 2, 3)$ are defined by Eq. (13). Also, $Z'(i)$ is defined as below:

$$Z'(i) = \left[(1-\varepsilon)Z(i)_1^{-} + Z(i)_2^{-} + \varepsilon Z(i)_3^{-}\right]^{1/2} + \left[(1-\varepsilon)Z(i)_1^{+} + Z(i)_2^{+} + \varepsilon Z(i)_3^{+}\right]^{1/2}$$

The PAF value for each decision alternative is determined as follows:

$$Z(i) = \frac{\left[(1-\varepsilon)Z(i)_1^{-} + Z(i)_2^{-} + \varepsilon Z(i)_3^{-}\right]^{1/2}}{Z'(i)},\ (i = 1,\ 2,\ \cdots, n) \tag{14}$$

In Eq. (14), $Z(i)$ represents the projection function value of the evaluation vector $x_i(\otimes)$ on a previously defined projection direction $e = (1-\mu, 1, \mu, \omega_1, \omega_2, \cdots, \omega_m)$, where $\varepsilon \in [0, 1]$ indicates the importance or preference coefficient, and $\omega_j (j = 1, 2, \cdots, m)$ is the weight vector of criterion S_j.

For any $i = 1, 2, \cdots, n$, $j = 1, 2, \cdots, m$, and $\mu \in [0, 1]$, $\frac{1}{2}\left[(1-\mu)x_{i1j} + x_{i2j} + \mu x_{i3j}\right]$ is the only expected value of alternative A_i with respect to criterion S_j. Based on the assumption above, the projection function value, $Z(i)$, determines the relative closeness of alternative i to the ideal optimal and critical alternatives.

Findings

The building industry is one of the largest industries in the studied developing country in terms of capital and the number of staff involved. Rapid population growth and increased demands have resulted in the need to reduce the construction project time requirements. Also, the lack of return on investment has created the need to transform traditional building industry practices by applying new technologies. On the other hand, the need to utilize and localize manufacturing technologies in line with the growth of each community, besides the use of technologies in other industries, is entirely different from the mere application of technologies. These needs sometimes lead to innovations or TT. In the TT process, precise solutions, similar to those described in this section, should be applied to rank TT models systematically.

In this section, to present the Shannon-PAF model, an illustrative example of building industry is proposed, and the selected TT models are ranked. According to the research path (Exhibit 5), the initial step included identification of the repeated evaluation criteria in Exhibit 1. Also, TT models, described in the literature review section, were collected. As explained in the methodology section, a literature review was carried out, and 34 open interviews were conducted to determine the TT models and evaluation criteria. All collected information from this stage was then presented to the focal group for basic screening. Thirty-four individuals, who had been interviewed in the previous step, were in the focal group. The snowball sampling method was used to select these experts. At the beginning of the study, the next potential experts were introduced by interviewees during open interviews. All of the experts cooperated with the authors throughout the study, were from six building companies in the developing country. A focal group session was used to identify and finalize TT methods applicable in the current case study. These methods included reverse engineering, foreign direct investment, turnkey, import of capital goods and machinery, and buyback contracts. Since screening and finalization of TT models, obtained from the literature review and open interviews, are not the primary objectives of this study, comprehensive explanations about the computational methods, analysis of the focal group data, and numerical results are presented in APPENDIX A.

Moreover, after holding the focal group, eighteen out of 44 evaluation criteria, described in Exhibit 1, were omitted. In the next stage, the Delphi method was applied to determine the final evaluation criteria. The questionnaires were used as the study tools, and the information of the questionnaires was analyzed in the Statistical Package for the Social Sciences (SPSS). To support the available information for the Shannon-PAF method, as the primary objective of this study, all data analyses, computational methods, and numerical data regarding the application of the focal group and Delphi panel for finalizing the evaluation criteria are presented in APPENDIX B. In brief, after three rounds of sending, receiving, and analyzing the information, the following six evaluation criteria were finalized, based on the Delphi panel results. TT models were studied based on these six main criteria:

- Research budgets
- Professional human resources
- Technology adaptability
- Familiarity with the market and technology
- Relative organizational capability
- The time needed to acquire a technology

In every industry, since TT should be in line with the recipient's conditions, it is necessary to establish criteria, which better provide adaptability to the new environment for a transferred technology. After finalizing the TT methods and evaluation criteria, according to the steps described in the methodology section, the opinions of thirty-four experts about the value and importance of each TT method against the finalized evaluation criteria were gathered and converted into three-parameter gray numbers and then averaged.

The resulting decision matrix, which is the average of 34 converted matrices, is displayed in Exhibit 7. Based on the Shannon entropy method, the weight of each criterion was calculated regardless of the external weight (Exhibit 8). Eqs. 6–9 were applied in Exhibit 7 to determine the weights represented in Exhibit 8 (Hwang & Masud, 2012; Kamfiroozi et al., 2012). In the final stage, the rank of each TT method (alternative) was determined using the PAF method by applying Eqs. 11–14 (Dang, 2009). Exhibit 9 presents the results of the PAF method. To apply the equations in the methodology section for Shannon and PAF algorithms, MATLAB software (Matrix Laboratory) was used to write the corresponding codes. Exhibits 7, 8, and 9 present the results.

Implications for Engineering Managers

When a project or industry requires a TT, similar to the one described in this research, selection of the right methodology, offering the most accurate and comprehensive way for ranking TT methods, plays an indisputable role in the success and development of the project, company, or industry. By controlling uncertainty in three stages, the proposed model can help engineering managers to find the best TT model in their projects. In addition to accuracy, while ranking different TT models in a project or firm, the proposed model offers a tangible step-by-step procedure, which makes tasks easier for engineering and R&D managers and allows them to save time in their projects. Since the proposed model includes three-parameter interval gray numbers, it will enable engineering managers to work with a small sample of experts in their TT method selection projects, which is a great advantage, especially in small firms. Based on the literature review, this study presented the repeated criteria in the TT method literature, which could be easily used as a guide when selecting a new TT method.

Conclusion and Discussion

TT is an essential element in enhancing the technology level of a country or firm and attaining sustainable development and competitive advantage. It requires attention to R&D centers,

Exhibit 7. The Decision Matrix

Criteria / TT Method	Research Budgets	Professional Human Resources	Technology Adaptability	Familiarity with the Market and Technology	Relative Organizational Capability	The Time Needed to Acquire a Technology
Reverse engineering	[0.225,0.325,0.425]	[0.273,0.373,0.473]	[0.562,0.662,0.762]	[0.546,0.646,0.746]	[0.433,0.533,0.633]	[0.285,0.385,0.485]
Foreign direct investment	[0.173,0.273,0.373]	[0.303,0.403,0.503]	[0.000,0.054,0.154]	[0.673,0.773,0.873]	[0.527,0.627,0.727]	[0.783,0.883,0.983]
Turnkey	[0.000,0.075,0.175]	[0.104,0.204,0.304]	[0.417,0.517,0.617]	[0.000,0.049,0.149]	[0.000,0.095,0.195]	[0.347,0.447,0.547]
Import of capital goods and machinery	[0.227,0.327,0.427]	[0.641,0.741,0.841]	[0.876,0.976,1.000]	[0.192,0.292,0.392]	[0.041,0.141,0.241]	[0.707,0.807,0.907]
Buyback contracts	[0.329,0.429,0.529]	[0.119,0.219,0.319]	[0.852,0.952,1.000]	[0.086,0.186,0.286]	[0.337,0.437,0.537]	[0.508,0.608,0.708]

Exhibit 8. Weight of the Evaluation Criteria (Results of the Shannon Method)

Criteria	Research Budgets	Professional Human Resources	Technology Adaptability	Familiarity with the Market and Technology	Relative Organizational Capability	The Time Needed to Acquire a Technology
Weight	0.1176	0.1271	0.1951	0.2874	0.2196	0.0532

Exhibit 9. Results of PAF Method

TT Method	Z^-	Z^+	Z	Rank
Reverse engineering	0.3779	0.0952	0.6658	1
Foreign direct investment	0.3952	0.2934	0.5357	4
Turnkey	0.0686	0.5254	0.2656	5
Import of capital goods and machinery	0.3817	0.2075	0.5777	2
Buyback contracts	0.3339	0.2522	0.5370	3

besides economic and political support for such activities. Given the rapid growth of new technologies and their importance in terms of national security, public welfare, and economic growth, negligence of these technologies may deprive countries/firms of many advantages. The importance of choosing TT methods has led many developing countries to test different types of technology acquisition methods for selecting the most appropriate ones. Meanwhile, countries and companies seek ways to make these technologies available as fast as possible. Considering all these limitations and obligations, evaluation and selection of TT methods for a specific case is a complex multidimensional issue. The new Shannon-PAF method, applied on three-parameter interval gray numbers, could help reduce uncertainties associated with human judgments, group decision-making, pairwise comparisons, and working with a small sample of experts; these factors are key points for engineering managers while managing a TT method selection project.

In the present case where the proposed method was applied based on the weights obtained from the Shannon method (Exhibit 8), familiarity with the market and technology and relative organizational capability were found to be the most important criteria. Since no external weight was assigned to the criteria, the studied TT methods were significantly different regarding these two criteria. This is of particular importance since a significant difference in the method scores for some specific criteria can be considered an advantage. In the construction industry, where the results of TT should be made available to a large number of consumers, and a large market can be conceived for the technology, market knowledge and familiarity with technology will play a decisive role in the success of technology selection and its transfer method. Based on the results, the most important criterion was familiarity with the market and technology. On the other hand, the time needed to acquire a technology criterion was the least important one. Although technology acquisition time is one of the most important criteria in the TT process, it lost its actual meaning and it was considered an insignificant factor due to the problems of the developing country in dealing with the international community for free transfer of technologies.

Besides, Exhibit 9 presents the ranking of TT methods for the building industry according to the results of the PAF method. Based on the supported explanations in the Shannon-PAF methodology section, the projection function value, $Z(i)$, determines the relative closeness of alternative i to the ideal optimal and critical alternatives. Therefore, the TT methods were ranked done with respect to the Z column in Exhibit 9. In this ranking, reverse engineering was found to be the best TT method. This study was performed at a time when the building industry of the studied country was facing problems in interaction with the international technology bodies; therefore, the reverse engineering method and import of capital goods and machinery were the most effective TT methods, respectively. The ranking of alternatives can be better understood if neighboring countries use their communication channels to facilitate the effective application of these two TT methods in the building industry of the studied country, respectively. Conversely, foreign investment methods, such as turnkey and FDI, were found to be unsuitable. The ranking highlighted the need for attention to domestic R&D centers. A common method of TT, such as FDI or turnkey, can be complicated and challenging in some cases, resulting in the loss of national technology and wasting time and money. Considering the current challenges of the studied country and the high capacity of local experts, reverse engineering was the best TT method, while the turnkey method was the least favorable. In the final stage of the research (Exhibit 5), the results were presented to experts and approved with regard to the obstacles and conditions of the industry and the country; this indicates the favorable performance of the model in actual projects.

Limitations and Future Studies

The present research had some limitations. Since the study concentrated on the building industry, and there were some data collection difficulties, the interviews generally included experts who were active in the private sector. Future research can examine the opinions of governmental experts. Regarding the time frame of the study and other limitations, the focal group approach and Delphi method were used to narrow down and finalize TT methods and evaluation criteria as the input of the Shannon-PAF method. In future studies, other approaches, such as formal content analysis and formal concept analysis, can be applied to compare the results. Besides, this study was conducted when the building industry of the country was experiencing obstacles in interaction with international technology bodies. Therefore, the repetition of the research and comparison of the results seem necessary after removing the barriers. Furthermore, due to competitions and some other strategic concerns, the studied technology cannot be named. Future studies can individually suggest some criteria for the evaluation of TT methods in other industries. Overall, sensitivity analysis and comparison of different methods of MCDM prioritization and ranking over both fuzzy and gray sets seem rewarding.

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Appendices

Appendix A

Explanations, Computations, and Analysis of Focal Group Method

According to previous researches, including studies conducted by Gatti (2005), Batchelor and Briffa (2011), and De FA Obregon et al. (2016), to omit less important criteria or items, focal group sessions can integrate experts' opinions. As described earlier in the manuscript, the focal group approach was used to finalize TT methods. For this purpose, a total of 34 individuals, interviewed in the first stages of the study, were included in the focal group. The snowball sampling method was used to select these experts. Also, one of the nonvoting researchers participated in focal group meetings as a moderator, recorded the experts' opinions for the final analysis. Exhibit 1A presents the experts' views in the focal group to narrow down TT methods, previously gathered from the literature review and open interviews.

The experts were asked to express their opinion about each TT method based on a nine-point scale, where one represented "not important at all", and nine represented "absolutely essential". The maximum score of a TT method was 306, and its minimum score was 34. Based on the information presented in Exhibit 1A and the viewpoints of experts in the focal group, five out of 14 TT methods, including reverse engineering, foreign direct investment, turnkey, import of capital goods and machinery, and buyback contracts, obtained the highest scores and were finalized. Due to the significant gap between the scores of these five methods and other TT methods, experts in the focal group decided to select five most rewarding methods in consultation with the group moderator.

Exhibit 1A. Results of the Focal Group Session for Selecting TT Methods

No.	TT Method	Score	Standard Deviation	Rank
1	Human exchange and employment	122	0.63	9
2	Acquisition	143	0.71	6
3	Equity investment	124	0.78	8
4	Training and education	134	0.68	7
5	Reverse engineering	303	0.81	1
6	Foreign Direct Investment (FDI)	298	0.79	2
7	Turnkey	280	0.58	5
8	Joint ventures	110	0.77	10
9	Licensing	86	0.61	13
10	Import of capital goods and machinery	286	0.73	4
11	Buyback contracts	290	0.55	3
12	Alliance	95	0.61	12
13	Outsourcing	101	0.59	11
14	Contract-out research and development	85	0.56	14

Appendix B

Explanations, Computations, and Analysis of the Delphi Method

The focal group approach can be used as an early auxiliary stage in quantitative studies (Khan et al., 1991). Considering the large number of evaluation criteria based on the literature review and open interviews, the focal group method was applied before the Delphi panel for early screening and rapid removal of evaluation criteria, which were considered to be of very low importance to the experts. In the following step, while applying the Delphi method, fewer rounds were used to determine the final criteria to rank the selected TT methods. Thirty-four individuals, interviewed in the first stages of the study, participated in the focal group. The snowball sampling method was used to choose these experts. They were asked to express their opinion about each criterion based on a nine-point scale, where one represented "not an important criterion at all", and nine represented "an absolutely essential criterion". Therefore, the maximum and minimum scores of TT methods were 306 and 34, respectively. According to the opinions of experts in the focal group, as presented in Exhibit 1B, 18 out of 44 original criteria were omitted.

There was a significant gap between the scores of 26 criteria and the scores of the other 18 criteria. These 18 criteria were as follows: type and attractiveness of technology; technology life cycle; technology change rate; complexity degree of technology; environmental factors; legal infrastructure; The necessity for the acquisition of technology; effect of technology on other industries; growth of technology attractiveness; cost of technology development; channels of technology diffusion (formal and informal); balance mechanism (internal and external organization); R&D resources (assets and abilities); infrastructural factors (physical, economic, social, technological, etc.); lost opportunity cost; government policies; organization size; and mind-set of technology donor and recipient. Therefore, experts in the focal group, in consultation with the group moderator, decided to omit these 18 criteria, which had the lowest scores. They only included the remaining 26 criteria in the Delphi method.

In the next step, to identify the final evaluation criteria according to the experts' opinions, we used the Delphi method, as well as the designed questionnaires. The Delphi method is generally suitable for collecting and refining the experts' opinions and judgments through repeated surveys when there is a lack of empirical data (Cottam et al., 2004; Edwards et al., 2011; Eycott et al., 2011; Ruivo et al., 2019). Based on previous researches, including studies conducted by Cottam et al. (2004), and Von der Gracht (2008), to analyze questionnaires, which were designed in three rounds of the Delphi method, the Average Percentage of Majority Opinions (APMO) was employed to produce the cutoff rate and to determine whether consensus could be reached. Equation 1B was used to calculate APMO:

$$APMO = \frac{\text{Majority Agreements} + \text{Majority Disagreements}}{\sum \text{Opinions Expressed}} \tag{1B}$$

In equation 1B, the majority of experts' agreements or disagreements for each criterion were defined with respect to

Exhibit 1B. Results of the Focal Group Session for Omitting Less Important Criteria in the First Screening

No.	Criteria	Score	Standard Deviation	Rank
1	Quality of contracting and implementation	175	0.73	21
2	Research budget	298	0.55	2
3	Professional human resources	300	0.61	1
4	Technology adaptability	285	0.59	4
5	Familiarity with the market and technology	289	0.56	3
6	Nature of technology	212	0.71	12
7	Characteristics of the donor organization	199	0.52	15
8	Policies of donor organization	263	0.71	10
9	Policies of recipient organization	193	0.62	18
10	The appropriate type of partnership between donor and recipient	202	0.61	14
11	Type and attractiveness of technology	87	0.61	22
12	Technology life cycle	56	0.64	27
13	Technology change rate	45	0.60	30
14	Availability of diverse supply resources	219	0.53	11
15	Complexity degree of technology	37	0.53	32
16	Environmental factors	42	0.61	31
17	Legal infrastructure	34	0.67	33
18	Competitive (strategic) effect of technology	194	0.63	17
19	Position of technology in the organization	265	0.66	8
20	Relative organizational capability for a technology	289	0.63	3
21	The time needed to acquire a technology	278	0.73	5
22	The necessity for the acquisition of technology	50	0.76	29
23	Effect of technology on other industries	76	0.78	25
24	Growth of technology attractiveness	76	0.72	25
25	Cost of technology development	45	0.66	30
26	Maximum of technology absorption	196	0.65	16
27	Maximum of market access	269	0.61	7
28	Maximum of alignment with technological changes	194	0.61	17
29	Organizational culture (innovative, supportive, bureaucratic, effective)	265	0.58	8
30	Channels of technology diffusion (formal and informal)	34	0.57	33
31	Balance mechanism (internal and external organizing)	78	0.65	23
32	R&D resources (assets and abilities)	34	0.70	33
33	Infrastructural factors (physical, economic, social, technological, etc.)	34	0.84	33
34	Lost opportunity cost	67	0.72	26
35	Government policies	55	0.53	28
36	Organization size	87	0.70	22
37	Mind-Set of technology donor and recipient	77	0.69	24
38	Educational background of technology donor and recipient	194	0.54	17
39	Technology maintenance costs	265	0.74	8
40	Managerial capabilities	185	0.68	20
41	Indigenous and environmental (restrictive) factors	187	0.66	19
42	The potential effect of technology on the industry	264	0.65	9
43	Macro- and micro- environment of technology recipient	207	0.72	13
44	Regional and global policies	275	0.64	6

the percentage of experts' agreements or disagreements for each criterion. In this study, a rate above 50% represented the "majority" opinion. An opinion for or against each criterion was considered as the majority opinion when the rate was greater than 50%. Next, the number of majority agreements or disagreements was obtained based on the experts' comments, i.e., "agree" or "disagree". The total number of majority agreements and disagreements was divided by the total number of expressed opinions to determine the APMO value. Any criterion with a higher percentage of positive or negative expert opinion than the APMO value was included in the next round of Delphi analysis; otherwise, it was excluded from the next round. According to this explanation, in the following step, 26 criteria, approved by the focal group, entered the Delphi method to finalize the criteria for ranking TT methods.

The results of the first round of the Delphi method, presented in Exhibit 3B, showed that 10 out of 26 criteria were omitted in this round, while 16 criteria were analyzed in the second round. According to Exhibit 2B, APMO was 59.1% in the first round. Any criterion with the majority agreement or disagreement exceeding this value entered the second round of the Delphi method.

Exhibit 2B. APMO Cutoff Rate for Consensus in Delphi Round One

Delphi Round One (APMO)	
Majority agreements	404
Majority disagreements	36
Total opinions expressed	744
APMO	59.1%
Number of criteria reached consensus	16
Number of criteria to be omitted in round two of the Delphi method	10

Exhibit 3B. Delphi Round One Analysis

No.	Criteria	Agree No.	Agree %	Disagree No.	Disagree %	Total Opinion Expressed	Consensus
1	Quality of contracting and implementation	22	65	10	29	32	**Yes**
2	Research budget	30	88	2	6	32	**Yes**
3	Professional human resources	30	88	3	9	33	**Yes**
4	Technology adaptability	30	88	3	9	33	**Yes**
5	Familiarity with the market and technology	26	76	3	9	29	**Yes**
6	Nature of technology	9	26	16	47	25	**No**
7	Characteristics of the donor organization	24	71	6	18	30	**Yes**
8	Policies of donor organization	27	79	5	15	32	**Yes**
9	Policies of recipient organization	5	15	18	53	23	**No**
10	The appropriate type of partnership between donor and recipient	25	74	6	18	31	**Yes**
11	Availability of diverse supply resources	9	26	15	44	24	**No**
12	Competitive (strategic) effect of technology	9	26	16	47	25	**No**
13	Position of technology in the organization	22	65	6	18	28	**Yes**
14	Relative organizational capability for a technology	27	79	2	6	29	**Yes**
15	The time needed to acquire a technology	23	68	8	24	31	**Yes**
16	Maximum of technology absorption	9	26	16	47	25	**No**
17	Maximum of market access	10	29	18	53	28	**No**
18	Maximum of alignment with technological changes	24	71	7	21	31	**Yes**
19	Organizational culture (innovative, supportive, bureaucratic, effective)	22	65	9	26	31	**Yes**
20	Educational background of technology donor and recipient	9	26	16	47	25	**No**
21	Technology maintenance costs	10	29	16	47	26	**No**
22	Managerial capabilities	25	74	5	15	30	**Yes**
23	Indigenous and environmental (restrictive) factors	23	68	9	26	32	**Yes**
24	The potential effect of technology on the industry	24	71	6	18	30	**Yes**
25	Macro- and micro- environment of technology recipient	9	26	16	47	25	**No**
26	Regional and global policies	9	26	15	44	24	**No**
	The majority agreed/disagreed or total	404		36		744	

The Results of the Second Round of the Delphi Method, Presented in Exhibit 5B, Showed that among 16 Criteria in This Round, Four Criteria Were Omitted, while the Remaining Criteria Were Analyzed in the Third Round of the Delphi Method. According to Exhibit 4B, APMO Was 69% in the Second Round. Any Criterion with the Majority Agreement or Disagreement above This Value Was Included in the Third Round.

The results of the third round of the Delphi method, presented in Exhibit 7B, showed that among 12 criteria in this step, six criteria were omitted, and six criteria were included. The six remaining criteria, all of which were of high importance based on the third round of the Delphi method, were also approved by the Delphi panel experts. According to the data presented in Exhibit 6B, APMO was 79% in the third round.

Based on the final results of the Delphi panel in Exhibit 7B, out of 44 criteria, gathered from the literature review and open interviews, six criteria, including research budget, professional human resources, technology adaptability, familiarity with the market and technology, relative organizational capability for a technology, and the time needed to acquire a technology were considered as the final evaluation criteria in the proposed research methodology for ranking the selected TT methods.

Exhibit 4B. APMO Cutoff Rate for Consensus in Delphi Round Two

Delphi Round Two (APMO)	
Majority agreements	330
Majority disagreements	0
Total opinions expressed	475
APMO	69%
Number of criteria reached consensus	12
Number of criteria to be omitted in round three of the Delphi method	4

Exhibit 5B. Delphi Round Two Analysis

No.	Criteria	Agree No.	Agree %	Disagree No.	Disagree %	Total Opinion Expressed	Consensus
1	Quality of contracting and implementation	13	38	16	47	29	**No**
2	Research budget	31	91	2	6	33	**Yes**
3	Professional human resources	29	85	3	9	32	**Yes**
4	Technology adaptability	32	94	1	3	33	**Yes**
5	Familiarity with the market and technology	28	82	4	12	32	**Yes**
6	Characteristics of the donor organization	24	71	6	18	30	**Yes**
7	Policies of donor organization	27	79	5	15	32	**Yes**
8	The appropriate type of partnership between donor and recipient	25	74	6	18	31	**Yes**
9	Position of technology in the organization	26	76	6	18	32	**Yes**
10	Relative organizational capability for a technology	30	88	2	6	32	**Yes**
11	The time needed to acquire a technology	28	82	5	15	33	**Yes**
12	Maximum of alignment with technological changes	26	76	4	12	30	**Yes**
13	Organizational culture (innovative, supportive, bureaucratic, effective)	14	41	9	26	23	**No**
14	Managerial capabilities	15	44	5	15	20	**No**
15	Indigenous and environmental (restrictive) factors	14	41	9	26	23	**No**
16	The potential effect of technology on the industry	24	71	6	18	30	**Yes**
	The majority agreed/disagreed or total	330		0		475	

Exhibit 6B. APMO Cutoff Rate for Consensus in Delphi Round Three

Delphi Round Three (APMO)	
Majority agreements	216
Majority disagreements	81
Total opinions expressed	376
APMO	79%
Number of criteria reached consensus	6
Number of criteria to be omitted in final Delphi round	6

Exhibit 7B. Delphi Round Three Analysis2

No.	Criteria	Agree		Disagree		Total Opinion Expressed	Consensus
		No.	%	No.	%		
1	Research budget	31	91	2	6	33	**Yes**
2	Professional human resources	28	82	3	9	31	**Yes**
3	Technology adaptability	29	85	2	6	31	**Yes**
4	Familiarity with the market and technology	32	94	1	3	33	**Yes**
5	Characteristics of the donor organization	18	53	12	35	30	**No**
6	Policies of donor organization	19	56	10	29	29	**No**
7	The appropriate type of partnership between donor and recipient	12	35	18	53	30	**No**
8	Position of technology in the organization	6	18	22	65	28	**No**
9	Relative organizational capability for a technology	31	91	2	6	33	**Yes**
10	The time needed to acquire a technology	28	82	6	18	34	**Yes**
11	Maximum of alignment with technological changes	11	32	20	59	31	**No**
12	The potential effect of technology on the industry	12	35	21	62	33	**No**
	The majority agreed/disagreed or total	216		81		376	