Optimal planning of university technology transfer measures with DANP-Fuzzy FlowSort and an extended multi-objective PROMETHEE V

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ABSTRACT This work offers an integrated methodological framework for decision support in planning the implementation of measures that address the barriers of university technology transfer. The planning problem consists of two parts: (1) identifying the high priority measures, and (2) optimally implementing these measures over a specified planning horizon subject to resource constraints. Treated as a multiple criteria sorting problem under uncertainty, the high priority measures are determined via fuzzy DEMATEL and ANP for evaluating the barriers, and the fuzzy FlowSort for classifying the priority of the various measures. Then, an extended multi-objective extension of the PROMETHEE V is offered to determine the degree of implementation of the high priority measures over multiple periods. Demonstrated in an actual case study with 29 identified measures under 24 previously known barriers, findings reveal six high priority measures, which include designing a sustained partnership, engaging in joint research ventures, establishing partnerships from international financial institutions, streamlining objectives to full support of the technology readiness levels, establishing a holistic system approach towards technology readiness levels, and establishing agreements to have access to the industry laboratory facilities. The implementation plan, represented as a set of Pareto optimal solutions, is obtained through the AUGMECON algorithm for the $\varepsilon$-constrained multi-objective linear programming formulation of the extended PROMETHEE V. A layer of sensitivity analysis was performed to test the robustness of the results to changes in the parameters. Finally, policy insights are provided to key decision-makers for advancing UTT.

INDEX TERMS university technology transfer; multi-period planning; analytic network process; fuzzy FlowSort; PROMETHEE V; multi-objective linear programming

I. INTRODUCTION
Following the interpretation of Mitev and Venters [1] and Swan et al. [2], university technology transfer (UTT) can be defined in two modes. The first mode (Mode 1 UTT) refers to the conventional role of universities to conduct basic research and transfer knowledge and learning to society through education. The second mode (Mode 2 UTT), the one considered here, refers to the commercialization of discoveries that originate from applied research or innovation studies in universities. Evidence of the latter’s pivotal role in regional economic growth is widely acknowledged [3]. In general, UTT is among the most studied topic in the technology transfer literature. In fact, among the domain works published in the years 1970-2019, 21% focuses on UTT [4]. For brevity, the discussion of these works is omitted here, but the reader is directed to the most recent review with emphasis on Mode 2 UTT performed by Miller et al. [5]. As a convention for the succeeding discussions, the use of the “UTT” acronym refers to Mode 2 UTT.

The UTT process begins with the consumption of research expenditures in innovation activities. In the university context, discoveries that originate from these activities are usually disclosed by the creators (or innovators) to the university’s technology transfer office (TTO), as required by law (e.g., the Bayh-Dole act). Most
laws governing UTTs in many countries are patterned after the United States (US)’ Bayh-Dole Act although some variations may occur. The TTO is responsible to apply these discoveries for registration in government intellectual property office (IPO). If registered, intellectual property (IP) rights are granted to the university. The commercialization phase of the UTT process lies within the licensing of the intellectual property rights (IPRs) to industrial partners. The execution of such licenses may yield the development of start-up companies or the production of new products and services by licensing companies. A portion of the gains obtained from the commercialization of licensed technologies is given to the universities as licensing income or more commonly known as royalties. The university may design its own policy to distribute some of the royalties to the laboratories, inventors or innovators, and university departments involved in the technology development as an incentive. The UTT process, as adopted from Friedman and Silberman [6], is presented in Fig. 1.

In their comprehensive review, Miller et al. [5] determine four research themes in the UTT literature. The first theme concerns the tension between basic research and commercialization. Commercialization efforts urge academics to pursue applied research; however, basic research usually provides a better academic standing because such works are more citable than their applied counterpart. This tension has become a barrier in the UTT process because academics become less motivated to pursue applied work, which is more inclined to the technology commercialization goal, especially with the academic culture favoring basic research. The second theme is on stakeholder relationships. Managing the UTT process involves a complex social structure that is composed of multiple stakeholders with different vested interests. Consolidating stakeholder differences to facilitate effective UTT has been an outstanding challenge in the current literature (e.g., [5]). The third theme is UTT performance. In the literature, UTT performance is commonly assessed by some portion of the gains obtained from the commercialization of licensed technologies. This is performed under the practical assumption that such an initiative provides a natural extension in managerial decision-making following the need for measures as solutions (or approximations thereof) to address these barriers. A multitude of measures may be developed to address the UTT barriers; each one targeting specific aspects of the barriers because no measure can be possibly encompassing that addresses the manifold and complex aspects of these intertwined barriers.

Although the work of Miller et al. [5] is comprehensive, it was intended to provide a general view of the problems reported in UTT studies instead of presenting specific UTT barriers. The work of Quiñones et al. [8] addresses this gap. In their study, 24 specific UTT barriers were obtained from a systematic literature review and the subsequent Delphi process. The discussion of the 24 UTT barriers is reserved in the succeeding section of this study. The subsequent publications by the same research team investigated the intertwined relationships of these barriers [11] and the use of these interrelationships in prioritizing the barriers [12]. However, the development and prioritization of strategies (or measures) for addressing these barriers remain unresolved in the current literature, which is a major gap as such an initiative provides a natural extension in managerial decision-making following the need for measures as solutions (or approximations thereof) to address these barriers.

In this study, various measures are developed to address the 24 UTT barriers of Quiñones et al. [8]. In the multi-criteria sorting problem addressed in this work, the measures are considered as the “alternatives” to be sorted. On the other hand, the 24 UTT barriers are assumed as the attributes (or criteria) by which the alternatives are evaluated. This assumption is valid in the sense that the sorting problem is performed as a way to discriminate certain measures from others. This is performed under the practical assumption that
institutions have a limited capacity to implement these measures, which warrants their prioritization. The sorting process will, therefore, depend on the measures’ (as alternatives) degree of contribution in addressing the UTT barriers (as the attributes). To account for the influence of the interdependencies of the UTT barriers, this work makes use of Quiñones et al.’s [11] results to estimate the relative weights of barriers considering their intertwined relationships.

Despite the number of MCS methods available in the literature, the outranking approach, usually based on Élimination et Choix Traduisant la Réalité (ELECTRE) and Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) gains the highest number of publications [13], [14], [15], [16]. Among the PROMETHEE-based MCS methods, the FlowSort [17] has been gaining the most attention, due to its most natural extension of the PROMETHEE for sorting problems [18]. In addition, the need to incorporate judgment uncertainty within the FlowSort gives rise to the consequential use of the fuzzy set theory [19]. The integration of fuzzy sets in the FlowSort [20] provides a mathematical platform in addressing imprecision and uncertainty, especially when decision-makers elicit judgments within the algorithm of the FlowSort. Thus, the fuzzy FlowSort (F-FlowSort) approach offered by Campos et al. [20], with subsequent more recent variations introduced by Pelissari et al. [21] and Moheimani et al. [22], is adopted in this work. On the other hand, the estimation of the barrier weights based on their interdependencies is performed using the integrated fuzzy DEMATEL and analytic network process (ANP), coined as the fuzzy DANP method. Accordingly, the results of the fuzzy DEMATEL have already been reported by Quiñones et al. [11], leaving the ANP for implementation in this work. The weights along with the measures’ degree of contribution in addressing the UTT barriers serve as inputs to execute the sorting process. The proposed methodological sorting procedure expressed here is implemented to address the following research question: Among the set of measures that can be employed to address the UTT barriers, which subset of measures must be provided with high priority? In practice, answering this question is essential in allocating limited resources to measures for addressing UTT barriers. Finally, a multi-period planning problem for the allocation of resources to the priority measures is considered in this work, following a proposed multi-objective extension of the PROMETHEE V, originally developed by Brans and Mareschal [23]. The methodological exercise performed here also demonstrates how MCDM methods can be used to obtain solutions to real-world problems. Specifically, to address the identified gaps in the domain literature, this work (1) defines the measures in addressing UTT barriers through a focus group discussion, (2) demonstrates a soft computing solution (i.e., integrated DANP and F-FlowSort) to identify the high priority measures, and (3) conducts an extended multi-objective PROMETHEE V to provide an optimal multi-period plan in the implementation of high priority measures. This overarching approach has not yet been espoused in the literature, and is first demonstrated in this work. The case of the UTT planning problem of a premier technological state university in the Philippines, which is the same case discussed in Quiñones et al. [8], Quiñones et al. [11], and Quiñones et al. [12].

The remainder of this paper is organized as follows. A review of the domain literature is provided in Section 2. Some preliminaries of the methods are presented in Section 3. Section 4 details the proposed methodological approach. To ensure that the decision is not coming from whimsical judgments, sensitivity analysis of the parameters is shown in Section 5. Discussion of the results is highlighted in Section 6, and managerial and policy insights are offered in Section 7. It ends with a discussion of some concluding remarks and possible future works in Section 8.

II. LITERATURE REVIEW

A. University technology transfer

Universities play a crucial role in expanding the range of existing knowledge that defines the twenty-first century and are accountable for making UTT a strategic process in promoting the economic potential of new technologies [24], [25], [11]. Since the enactment of the Bayh-Dole Act in the US in 1980 has allowed universities to own patents arising from federally supported research, the level of university-industry technology transfer has increased dramatically [26], [27]. University-industry partnership increases the convergence of firms’ market-based experience, thus encouraging valuable technologies and innovations [28]. Technology and innovation have been the initiator of development in the economy and society over the past years. Hayter et al. [29] found that technology transfer is often associated linearly, for instance, with patenting and licensing. In the perspective of Pagani et al. [30], technology transfer is a complex process yet effective in mitigating a range of outcomes (i.e., impacts on the market, politics, and social development).

On the other hand, United Nations Industrial Development Organization (UNIDO) defines technology transfer as “the process by which a collected entity (i.e., an act of making a product, application of a technique, or performance of a service) is communicated, partially or entirely, from one party to another.” Also, Quiñones et al. [11] added that it embodies a method of disseminating and commercializing IP by transforming it into products available to the general public. Soares et al. [31], on the other hand, emphasized that academics still need to acquire essential IP knowledge (e.g., new techniques in drafting patents and claims).

Technology transfer made significant advancements in economic activities. It has long been a top priority for university faculty, practitioners, academics, and governments to improve national competitiveness and has become highly institutionalized globally [32]. For instance,
the Egyptian government has implemented the need for innovation by urging its universities to be more involved in the technology transfer process considering the aid of external funding sources [33]. Apart from their conventional aim of teaching, universities have also extended their engagement with industry and community [11]. The changes brought by the knowledge transfer from the university-industry (UI) made Italy more innovative with its potential and dynamics [34]. Meanwhile, Fischer et al. [35] remarked that the gradual increase in the involvement of universities in Brazil in technology development heightens innovation. In addition, through UTT initiatives, Dagiliūtė and Liobikienė [36] observed that higher education institutions (HEIs) in Lithuania have a significant contribution to environmental sustainability by being the key actor in shaping an ecologically sound society.

Despite its role, UTT faces a set of innumerable barriers and corresponding response measures that need attention. The motivations and capabilities of universities and firms influence their readiness to engage in technology transfer in a UI relationship [37], [12]. Recognizing the presence of barriers, lately highlighted in the work of Quinones et al. [11], aids in identifying possible critical problems that may arise during the UTT process, which can then be used to guide stakeholders in decision-making.

B. Barriers of university technology transfer

For the past 30 years, scholars have produced deep literature highlighting the phenomenon of technology transfer from research universities [38], as well as closely related concepts such as academic engagement [39], academic entrepreneurship [29], and science commercialization [40]. However, these constructs are hindered by various barriers [41]. Recognizing the existence of identified barriers in UI collaboration better exposes the problems and challenges in the collaboration process [37].

Brescia et al. [42] observed that university TTOs help generate income for universities from licensing patents and creating spin-offs, but in actual practice, they increasingly pursue a broader mission related to nurturing UI collaboration and supporting university research. From an industry point of view, UTT can provide a source of new knowledge, skills, and equipment that can aid innovation and economic development [43]. Thus, this makes the lack of appropriate partners a barrier for UTT. In addition, cultural differences between universities and industries are also considered another barrier [9]. Also, some industries may experience that universities cannot fully cooperate with the industrial culture [44]. Some studies have indicated that universities and industries have limited knowledge of opportunities engaging both parties with UTT [45]. Furthermore, Shen [9] has identified the lack of recognition for UI linkages as a barrier to accessing suitable partners. On the other hand, Belkhouja and Landry [46] considered the lack of venture capital as another barrier of UTT, associated with the lack of funding and guidance for venture capitalists.

Its primary role is to facilitate the formation of university spin-offs as they provide crucial risk capital and offer assistance to new firms [47].

In some studies on technology transfer in universities and industries, various institutional barriers exist [9]. The inconsistencies of the rules and regulations implemented by universities, industries, and government funding agencies also hinder the implementation of the UTT process [38], [9]. In order to achieve an effective and productive collaboration, it requires an acceptable set of rules on IPRs to uphold the trust among partners [48]. Institutional bureaucracy and inflexibility of the university are also considered a hindrance to UTT. Evidence from various studies suggests that it hinders the organizational functions between collaborations [49]. Another barrier of UTT is the shortage of resources [50] (i.e., including technological knowledge, infrastructure, financial and human capital) which limits the innovation of university and industry collaboration. Thus, this barrier significantly affects the UTT and could also lead to various resulting barriers in successful UI collaboration. These include the high risk of information leakage to competitors, which is also considered as one of the main hindrances of having a successful collaboration [51], [40] and the lack of rigorous reward systems in commercialization and publication initiatives [52].

Time constraint is also another barrier present during the UTT process [9], [53]. Faculty members of universities are constrained by their time to participate in various UTT initiatives on top of other functions related to research and instruction. Another barrier of UTT that scholars pointed out is that the knowledge developed by universities is too theoretical for practical purposes [9], [44], [51]. Shen [9] emphasizes that scholars admit that their developed research work is not aligned with the industry’s needs and interests. Furthermore, TTO should possess a good understanding of what the industry needs and what the university would develop to forge a meaningful collaboration [9]. Other barriers that are widely regarded in the UTT literature include the lack of accurate assessment and benchmarks for technology transfer, the lack of accurate evaluation [36], and the lack of willingness of the participant’s personal motivation [54]. Subsequent studies of Quiñones et al. [8], Quiñones et al. [11], and Quiñones et al. [12] have extensively discussed and enumerated most of these barriers. An attempt to identify the priority barriers was reported in Quiñones et al. [11] by analyzing their intertwined relationships.

C. Approaches for enhancing university technology transfer

With UTT, universities contribute to economic growth through the promotion of entrepreneurial activities [55], [56], [57]. Thus, understanding the UTT process in terms of evaluating its barriers and their composite relationships aids in making crucial decisions [11]. Promoting initiatives to address these barriers is a straightforward extension of prior efforts and some studies attempted to explore these...
initiatives or measures. For instance, Leahy and Lane [58] have identified the practices and the actors in disabling UTT barriers. Jasinski [59] also presented the crucial barriers for technology transfer in a transitional economy and provided relevant recommendations for short- and long-term measures for all main actors in small and medium enterprises (SMEs). Short-term measures include increasing technical license costs and consulting services, increasing inventions, proposing and maintaining cooperation with partners, employing experts, and expanding training. Long-term measures consist of forming joint research projects, increasing science and technology partnerships with local and foreign organizations, creating an innovative culture, and developing a science and technology information system. Yuan et al. [60] highlighted the significance of developing a university entrepreneurial approach to create value influencing UTT performance. They suggest that universities continuously construct, restructure, and plan their resources to develop new technologies, increase industry collaboration, and respond to changes.

On the other hand, policy-makers have institutionalized policies to enhance local knowledge flows to enable UTT and research collaborations [61], [62], [63]. For instance, several OECD governments have come to match the Bayh-Dole Act, legislation that motivates growth in UTT, and research collaboration [63]. Other governments have also provided incentives to those involved in collaborative research (e.g., National Cooperative Research Act of 1984, Philippine Technology Transfer Act of 2009). There are also research joint ventures subsidies (e.g., European Union’s Framework Programmes), shared use of expertise and laboratory facilities (e.g., Industry-University Cooperative Research Centers), and support for incubators [64]. A strategic alliance is a scheme in UTT that involves mutually beneficial inter-organization arrangement that exchanges, shares, or co-develops either products, technologies, or services [65]. International collaborations are crucial as possible differences between collaborating partners (e.g., culture and organizational structures) may impede the managements’ leverage towards international innovations [66], [67].

UTT could also be implemented through collaborative joint publication and patent application (i.e., international university-university, university-industry) [67]. The domain literature also suggests patenting and spin-offs subject to the well-defined metrics [68], [69]. Some works highlight organizational support such as information dissemination (e.g., research projects, technology) and incentives [70], [71], [72], [73]. Wu et al. [73] emphasized that individual attitude and their engagement activities towards commercialization have more influenced UTT than UI collaboration and the assistance provided by university administrators. The motivation of UTT is more pronounced by the UI collaboration rather than through industry-funded research. Thus, funding does not offer a greater chance of UTT. University also needs experts in identifying and managing the commercial value of research outcomes [74], [75], [76]. TTO has a significant role in developing university linkages and UTT by implementing registration of research outputs and commercialization of technologies [69], [73], [77], [78], [76]. Co-locations could be implemented to catalyze idea and information sharing between industry and university researchers [79]. Despite these advances, however, limited works are available on evaluating the efficacy of these measures in addressing UTT barriers, which is a targeted approach in designing specific institutional agenda for UTT.

III. PRELIMINARIES

Although the proposed methodological framework includes the fuzzy DEMATEL approach, the reader is left to refer to such procedure in the available literature (e.g., [11], [80], [81]). Thus, this section provides the introductory concepts of the ANP, fuzzy set theory, PROMETHEE, and fuzzy FlowSort. Note that, in particular, the ANP supermatrix approach demonstrated in this work merely extends the total relation matrix reported by Quiñones et al. [11] in their fuzzy DEMATEL application in analyzing the intertwined relationships of the UTT barriers.

A. Analytical network process

The ANP was developed by Saaty [82] as an extension of the analytic hierarchy process (AHP) [83] to overcome the problem of interdependence and feedback among criteria and alternatives in an MCDM problem. While AHP represents a framework with a unidirectional hierarchical relationship, the ANP allows for complex interrelationships among criteria and alternatives [82]. The complex interrelationships form a directed graph wherein the edges represent the dominance of a decision component to other decision component(s). The eigenvector method, prescribed in the AHP, is described as the exact way of estimating the relative local priorities of these elements. In obtaining the ratio-scale priority weight vector $w$ of $n$ elements, Saaty [83] proposed an eigenvalue problem described as follows:

$$Aw = \lambda_{max}w$$  \hspace{1cm} (1)

where $A$ is the positive reciprocal pairwise comparison matrix and $\lambda_{max}$ is the maximum eigenvalue of matrix $A$. For consistency of judgment $\lambda_{max} = n$; otherwise, $\lambda_{max} > n$. The consistency index $CI$ and consistency ratio $CR$ are used to measure the consistency of judgment as represented as:

$$CI = (\lambda_{max} - n)/(n - 1)$$  \hspace{1cm} (2)

$$CR = CI/RI$$  \hspace{1cm} (3)

where $RI$ is the mean random consistency index. The degree of consistency is acceptable if $CR \leq 0.10$ while decision-makers would be asked to reconsider the pairwise comparisons if $CR > 0.10$. 

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The global priority ratio scales are determined based on the synthesizing principle of the supermatrix, where column values describe the influence of row elements on column elements, primarily obtained from local priority vectors. The transmission of influence along all possible paths in the decision structure is captured in the process by raising the matrix to large powers [84], and as long as the supermatrix representation is a primitive irreducible matrix in a strongly connected digraph, the initial supermatrix \( S \) will eventually converge to a limit supermatrix \( L \). The numerical approach of solving \( L \) is defined as:

\[
\lim_{p \to \infty} (S/\lambda_{\text{max}})^p = \lim_{n \to \infty} (\tilde{S})^p = L
\]

where \( p \) denotes an arbitrarily large number. Each column of the limit supermatrix is a unique positive column eigenvector associated with the principal eigenvalue [82]. This principal column eigenvector resembles the stable priorities of the limit supermatrix and can be used to measure the overall relative dominance of one element over another element in a network structure [82].

### B. Fuzzy set theory

Zadeh [19] developed the fuzzy set theory as an extension of classical set theory that addresses uncertainty and vagueness in information computing. A fuzzy set is characterized by a membership function that assigns a degree of membership ranging between 0 and 1.

Definition 1 [85]. Let \( \Delta \) be a universe of discourse. A fuzzy number can be represented by a fuzzy set \( F = \{x, \mu_F(x), x \in \Delta\} \) on a real number line, where \( \mu_F(x) \) is a membership function of \( x \) in \( F \). In a standard fuzzy set \( F \), each element is mapped to the closed interval \([0,1] \) by \( \mu_F(x) : \Delta \to [0,1] \) which includes all real numbers between 0 and 1, including 0 and 1. The set \([0,1]\) is a crisp set whereas any value that is represented between 0 and 1 indicates a partial truth.

There are several forms of a fuzzy number but the most widely used is the LR type triangular fuzzy number (TFN) [84]. A TFN \( \tilde{A} \) can be defined as a triplet \( \tilde{A} = (m, \alpha, \beta)_{LR} \) where \( m \) is the mean value of the fuzzy number \( \tilde{A} \), while \( \alpha \) and \( \beta \) are its left and right boundary values, respectively. The membership function of the TFNs can be defined as

\[
\mu_{\tilde{A}}(x) = \begin{cases} 
1 - \frac{x-m}{\alpha}, & (m - \alpha) < x \leq m \\
1 - \frac{x-m}{\beta}, & m < x \leq (m + \beta) \\
0, & \text{otherwise}
\end{cases}
\]

The representation of a TFN is shown in Fig. 2.

Definition 2. Let \( \tilde{A} = (m, \alpha, \beta)_{LR} \) and \( \tilde{B} = (n, \gamma, \delta)_{LR} \) be two TFNs and let \( \rho \) be a scalar quantity, then the arithmetic operations are as follows:

\[
\tilde{A} \oplus \tilde{B} = (m + n, \alpha + \gamma, \beta + \delta)_{LR}
\]

\[
\tilde{A} \odot \tilde{B} = (m - n, \alpha + \delta, \beta + \gamma)_{LR}
\]

\[
\rho \tilde{A} = (\rho m, \rho \alpha, \rho \beta)_{LR}
\]

![Figure 2. Representation of a TFN.](image)

### C. PROMETHEE

Developed by Brans [86], the PROMETHEE is one of the most prominent MCDM methods. Several works have utilized PROMETHEE in tourism [87], material selection [88], medical treatment [89], location selection [90], among others. PROMETHEE is based on the principle of outranking among alternatives. It consists of many types of variations which include the PROMETHEE I for partial ranking of alternatives and PROMETHEE II for the complete ranking of alternatives [91]. Other extensions include PROMETHEE III, PROMETHEE IV, PROMETHEE V, and PROMETHEE VI which were discussed in detail by Brans and De Smet [18]. The following describes the steps for PROMETHEE I and II:

**Step 1:** A kth decision-maker elicits judgment on alternative \( a \) where \( a \in A \) under criterion \( j \). The performance evaluation \( g_j^k(a) \) is aggregated under a pre-defined method such as the arithmetic mean method shown in (9).

\[
g_j(a) = \frac{1}{K} \sum_{k=1}^{K} g_j^k(a)
\]

where \( k = 1, 2, \ldots, K \).

**Step 2.** Calculate the deviation \( d_j(a, b) \) between two alternatives \( a \) and \( b \). This is obtained from the difference between the aggregate of experts’ evaluation with respect to criterion \( j \) as depicted in (10).

\[
d_j(a, b) = g_j(a) - g_j(b)
\]

**Step 3.** Determine the preference function \( P_j(a, b) \) using the intensity of preference associated with the deviation \( d_j(a, b) \) between two alternatives \( a \) and \( b \).

\[
P_j(a, b) = P_j(d_j(a, b))
\]
The value of $P_j(a, b)$ ranges from 0 to 1. As the preference function approaches the value 1, the experts’ preference of $a$ over $b$ increases. Six types of preference functions are introduced in the PROMETHEE method, which is presented in Appendix A. These preference functions require appropriate indiffernce and preference parameters. These parameters should be assigned with the consensus of the experts.

**Step 4.** The preference degree $\pi(a, b)$ of each ordered alternative is calculated by multiplying the criterion weight $w_j (\sum_j w_j = 1)$ to each aggregate preference function values $P_j(a, b)$.

$$
\left\{ \begin{array}{l}
\pi(a, b) = \frac{1}{m-1} \sum_{x \in A} \pi(a, x) \\
\pi(b, a) = \frac{1}{m-1} \sum_{x \in A} \pi(x, a)
\end{array} \right. (12)
$$

**Step 5.** Determine the outranking flows of each alternative for PROMETHEE I. The partial ranking of alternatives is provided by simultaneous comparisons of the positive outranking flows $Q^+(a)$ and negative outranking flows $Q^-(a)$. These are computed as follows:

$$
Q^+(a) = \frac{1}{m-1} \sum_{x \in A} \pi(a, x) \quad (13)
$$

$$
Q^-(a) = \frac{1}{m-1} \sum_{x \in A} \pi(x, a) \quad (14)
$$

Equation (13) shows by how much an alternative $a$ outranks all the other alternatives. On the other hand, (14) expresses by how much an alternative $a$ is outranked by all the other alternatives.

**Step 6.** Compute the net flow of each alternative for PROMETHEE II. The complete ranking of alternatives is determined by the net outranking flow of each alternative as expressed in (15).

$$
Q(a) = Q^+(a) - Q^-(a) \quad (15)
$$

If $Q(a) > Q(b)$, then alternative $a$ outranks $b$. Furthermore, if $Q(a) = Q(b)$, then $a$ and $b$ are indifferent.

**D.Fuzzy FlowSort**

FlowSort is a sorting methodology developed by Nemery and Lamboray [17] based on PROMETHEE for assigning alternatives $A = \{a_1, a_2, ..., a_l\}$ to completely ordered categories $C = \{c_1, c_2, ..., c_n\}$ predefined by limiting profiles $L = \{l_1, l_2, ..., l_p\}$ where $p = 1, 2, ..., o + 1$. A comprehensive theoretical discussion of the FlowSort method in which categories are defined by reference profiles can be found in Nemery and Lamboray [17]. An integration of the FlowSort method and fuzzy set theory using TFNs (hereby referred to as F-FlowSort) was introduced by Campos et al. [20], to address the ambiguity and imprecision in judgment elicitation. The computational procedural flow for the FlowSort and F-FlowSort are similar. The only difference is the arithmetic operations to be conducted in which the latter requires the operations of TFNs in Definition 2. The following are the steps for the F-FlowSort method [19]:

**Step 1.** Similar to PROMETHEE I and II, the first step of F-FlowSort consists of the elicitation of the $k$th decision-maker wherein $k = 1, ..., K$ to alternative $a_i$ under a criterion $j$, represented as $\tilde{g}_j^k(a_i) = (m_{ij}^k, \alpha_{ij}^k, \beta_{ij}^k)$. These performance evaluations are represented by TFNs using a predefined scale. The aggregate evaluation $\tilde{g}_j(a_i) = (m_{ij}, \alpha_{ij}, \beta_{ij})_{LR}$ is calculated using,

$$
\left( m_{ij}, \alpha_{ij}, \beta_{ij} \right)_{LR} = \left( \frac{1}{K} \sum_{k=1}^{K} \frac{1}{w_j} \sum_{k=1}^{K} a_{ij}^{k} \right)_{LR} = \frac{1}{K} \sum_{k=1}^{K} \frac{1}{w_j} a_{ij}^{k} \quad (16)
$$

**Step 2.** Calculate the deviation $\tilde{d}_j(a_i, l_p) = (m_{ijp}, \alpha_{ijp}, \beta_{ijp})_{LR}$ between an alternative $a_i$ and a $p$th limiting profile $l_p$. The difference between the aggregate of experts’ evaluation and predefined limiting profile with respect to criterion $j$ is calculated. The subtraction operation follows the operations for TFNs (see (7)).

$$
\left( m_{ijp}, \alpha_{ijp}, \beta_{ijp} \right)_{LR} = \left( m_{ij}, \alpha_{ij}, \beta_{ij} \right)_{LR} \ominus \left( m_{pj}, \alpha_{pj}, \beta_{pj} \right)_{LR} \quad (17)
$$

where $\tilde{g}_j(l_p) = (m_{pj}, \alpha_{pj}, \beta_{pj})_{LR}$

**Step 3.** Determine the preference function $P_j(a_i, l_p) = (m_{ijp}, \alpha_{ijp}, \beta_{ijp})_{LR}$ using the intensity of preference associated with the deviation $d_j(a_i, l_p)$ between alternative $a_i$ and limiting profile $l_p$. This expression is operated in (18):

$$
\left( m_{ijp}, \alpha_{ijp}, \beta_{ijp} \right)_{LR} = \left| P_j(m_{ijp}, P_j(m_{ijp}) - m_{ijp} - \alpha_{ijp}, P_j(m_{ijp} + \beta_{ijp}) - P_j(m_{ijp}) \right|_{LR} \quad (18)
$$

The preference function $P_j$ for each criterion $j$ should be defined based on the six criterion types presented in Appendix A.

**Step 4.** The fuzzy preference degree $\pi'(x, y) = (\tilde{m}, \tilde{\alpha}, \tilde{\beta})_{LR}$ of each alternative $x$ over an alternative $y$ is computed using the arithmetic operations on TFNs for all alternatives $x, y$ of $R_i = L \cup \{a_i\}$.

$$
(\tilde{m}, \tilde{\alpha}, \tilde{\beta})_{LR} = \left( \Sigma_{j=1}^{n} w_j m_{ijp}, \Sigma_{j=1}^{n} w_j \alpha_{ijp}, \Sigma_{j=1}^{n} w_j \beta_{ijp} \right) \quad (19)
$$

wherein the criterion weight $w_j$ is defined and $\sum_j w_j = 1$.
Step 5. Transform the $\pi'(x, y)$ into its corresponding crisp value. Utilizing Yager’s operator [92], the defuzzification of the preference degree $\pi(x, y)$ is as follows:

$$\pi(x, y) = \frac{3m - \pi + \beta}{3} \quad (20)$$

Step 6. Determine the positive, negative, and net flows of each alternative $x$ of $R_i$ using the following equations:

$$Q_{R_i}^+(x) = \frac{1}{|R_i|} \sum_{y \in R_i} \pi(x, y) \quad (21)$$

$$Q_{R_i}^-(x) = \frac{1}{|R_i|} \sum_{y \in R_i} \pi(y, x) \quad (22)$$

$$Q_{R_i}^0(x) = Q_{R_i}^+(x) - Q_{R_i}^-(x) \quad (23)$$

Step 7. The assignment of alternatives to the categories is similar to the FlowSort methodology [17]. Assuming that category $C_i$ has the upper limit $t_p$ and a lower limit $t_{p+1}$, two different assignment rules based on positive and negative flows are defined as follows:

$$C_{Q^+}(a_i) = C_i \text{ if } Q_{R_i}^+(t_p) > Q_{R_i}^+(t_{p+1}) \geq Q_{R_i}^-(t_{p+1}) \quad (24)$$

$$C_{Q^-}(a_i) = C_i \text{ if } Q_{R_i}^-(t_p) \leq Q_{R_i}^-(t_{p+1}) \quad (25)$$

On the other hand, the assignment rule based on the net flow is as follows:

$$C_Q(a_i) = C_i \text{ if } Q_{R_i}^0(t_p) > Q_{R_i}^0(t_{p+1}) \quad (26)$$

IV. METHODOLOGY

A. Case study background

The prevailing challenge of HEIs in the Philippines, both public- and private-funded, is the evident lack of innovative measures to address the barriers of UTT. Thus, a case study is conducted in one of the HEIs in central Philippines. The Cebu Technological University (CTU) has embarked on an effort in IP awareness, creation, protection, and commercialization in the same manner as other HEIs, e.g., the flagship University of the Philippines [88]. Furthermore, engaging in partnership with the Intellectual Property Office of the Philippines (IPOPHIL) has dramatically impacted the IP consciousness of CTU. The IPOPHIL holds that academic entrepreneurship may stimulate commercial innovation, economic development, and social development.

A notable surge in IP applications and registration of utility models, patents, copyrights, trademarks, and industrial designs have been observed in CTU during the years 2010-2022. With the financial support from the national government and university income, the university consistently received national recognition from the IPOPHIL as the Top Utility Model Filers and Top Registered Utility Models from 2009 to 2018. Moreover, the university’s significant contributions to product and process innovations were recognized by the Clarivate South and Southeast Asia Innovation Awards in 2020 and 2021.

Despite these major advances of CTU in producing IP assets, fewer than 400 innovations have reached the level of technology and business development readiness, and technologies have a lower transfer rate which translates to lower income for the institution. A few technologies have licensing agreements, while others have been shared through community extension. Despite the efforts of the university, industry partners, government agencies, and other stakeholders, the UTT process in CTU is still in its early stages of development [11]. Such insights may be captured when appropriate ways and tangible initiatives are holistically identified and resources are optimally allocated.

In this context, identifying measures for addressing the various UTT barriers and allocating appropriate resources for these measures, as in the case of a state institution, are critical for a strong technology transfer direction of the university.

B. Profile of the expert group

In order to establish the list of expert decision-makers, a purposive sampling technique was employed in the same manner with the previous works, e.g., Quiñones et al. [11] and Ocampo and Promentilla [94]. Eighteen (18) experts were selected based on their academic degrees, experiences, and academic positions associated with UTT activities. All these experts have worked in supervisory and managerial positions in the university for 2 to 30 years and came from different departments of the different university campuses. The qualifications were highlighted to build a group of expert decision-makers. Eighty-four percent of the decision-makers came from the university’s top and middle management, and the majority hold a Ph.D. or equivalent. The relevant qualifications of the decision-makers are provided in Table I.

| Decision maker | Years of experience in the university | Years of managerial positions | Functions |
|----------------|--------------------------------------|-----------------------------|-----------|
| 1              | 11                                   | 3                           | University Director |
| 2              | 11                                   | 14                          | Chairperson    |
| 3              | 23                                   | 11                          | Associate Dean |
| 4              | 40                                   | 30                          | University Director |
| 5              | 14                                   | 35                          | University Director |
| 6              | 21                                   | 14                          | Center Director |
| 7              | 5                                    | 25                          | University Director |
| 8              | 27                                   | 23                          | University Director |
| 9              | 6                                    | 9                           | Associate Dean |
| 10             | 5                                    | 5                           | University Director/College Dean |
| 11             | 10                                   | 4                           | Director |
| 12             | 8                                    | 15                          | Center Director |
| 13             | 23                                   | 13                          | Vice President |
| 14             | 10                                   | 2                           | Chairperson |
| 15             | 3                                    | 9                           | Chairperson |
| 16             | 23                                   | 15                          | Campus Director |
| 17             | 4                                    | 5                           | Center Director |
| 18             | 19                                   | 15                          | College Dean |

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C. Application of DANP-F-FlowSort

With the agenda of identifying priority measures in addressing the UTT barriers previously identified by Quiñones et al. [11], the proposed integration of fuzzy DANP and F-FlowSort was adopted. Note that the fuzzy DEMATEL part of the approach, a subcomponent of fuzzy DANP, was already performed in Quiñones et al. [11]. This leaves the ANP to be implemented in this work. Shown in Fig. 3 are the required steps of the proposed methodology.

The required steps are detailed as follows:

**Phase 1: Fuzzy DANP**

**Step 1.** Identify the set of UTT barriers. This study utilizes the list of UTT barriers (see Appendix B) as identified by Quiñones et al. [8] through a comprehensive literature survey and a Delphi process.

**Step 2.** Attain the crisp total relation matrix from the fuzzy DEMATEL method. In this study, the total relation matrix produced by Quiñones et al. [11] is utilized. See Appendix C.

**Step 3.** Obtain the limiting supermatrix and the corresponding global priority weights of the UTT barriers. To do this, the total relation matrix of Quiñones et al. [11] is first translated to a column stochastic total relation matrix (i.e., column normalization). The resulting matrix becomes the initial supermatrix of the ANP. Then, using (4), the limiting supermatrix is obtained, where each column represents the estimates of the priorities of UTT barriers. The global priority vector is shown in Table II.

| Code | Priority weight | Code | Priority weight |
|------|----------------|------|----------------|
| B1   | 0.0426         | B13  | 0.0418         |
| B2   | 0.0415         | B14  | 0.0423         |
| B3   | 0.0440         | B15  | 0.0400         |
| B4   | 0.0425         | B16  | 0.0411         |
| B5   | 0.0423         | B17  | 0.0428         |
| B6   | 0.0403         | B18  | 0.0427         |
| B7   | 0.0427         | B19  | 0.0399         |
| B8   | 0.0410         | B20  | 0.0403         |
| B9   | 0.0424         | B21  | 0.0417         |
| B10  | 0.0435         | B22  | 0.0392         |
| B11  | 0.0432         | B23  | 0.0392         |
| B12  | 0.0430         | B24  | 0.0402         |

**Phase 2: F-FlowSort**

**Step 4.** The expert group identifies the set of possible measures in addressing UTT barriers. Appendix D contains the list of measures available to university management in overcoming the various barriers, along with the codes assigned to each measure. These measures were obtained from a focus group discussion of the experts which represent the key decision-makers of the university regarding UTT initiatives.

---

**Figure 3. The DANP-F-FlowSort framework.**
Step 5. Define the preference function and the limiting profiles for each UTT barrier based on the identified classes. In this study, the types of preference function used are Type 2 (U-shaped criterion) and Type 3 (V-shape criterion). As assigned by the decision-makers, the corresponding indifference thresholds of Type 2 and preference thresholds of Type 3 for each barrier are shown in Table III. Three pre-defined classes (or categories) are introduced: “low priority”, “moderate priority”, and “high priority”. The decision-makers produced a set of limiting profiles \( L = \{ l_1, l_2, l_3, l_4 \} \) for each class. For all barriers (i.e., B1 to B24), \( l_1 = 7, l_2 = 5, l_3 = 3, \) and \( l_4 = 1 \).

Table III. Values of indifference \((q)\) and preference \((p)\) thresholds

| Barrier | Preference Type | \(q\) | \(p\) |
|---------|----------------|-------|-------|
| B1      | 2              | 0.50  | -     |
| B2      | 2              | 0.30  | -     |
| B3      | 2              | 0.30  | -     |
| B4      | 3              | 1.00  | -     |
| B5      | 3              | 1.00  | -     |
| B6      | 2              | 0.30  | -     |
| B7      | 2              | 0.50  | -     |
| B8      | 3              | 1.00  | -     |
| B9      | 2              | 0.50  | -     |
| B10     | 2              | 0.50  | -     |
| B11     | 3              | 0.80  | -     |
| B12     | 2              | 0.50  | -     |
| B13     | 3              | 1.00  | -     |
| B14     | 2              | 0.30  | -     |
| B15     | 3              | 1.00  | -     |
| B16     | 3              | 0.50  | -     |
| B17     | 3              | 1.00  | -     |
| B18     | 3              | 1.00  | -     |
| B19     | 3              | 1.00  | -     |
| B20     | 3              | 1.00  | -     |
| B21     | 2              | 0.50  | -     |
| B22     | 2              | 0.50  | -     |
| B23     | 3              | 1.00  | -     |
| B24     | 3              | 1.00  | -     |

Step 6. Construct the individual fuzzy evaluation matrix. Through a survey, the members of the expert group were asked to elicit judgments as to the degree of which a specific measure addresses a UTT barrier using a pre-defined scale. They were asked to elicit their judgment on the degree of capability of the measures in overcoming the barriers. The questions were stated as “What is the degree of implementation of the measure to a predetermined class, the assignment rule based on the net flow as defined in (26) is used. The sorting results are presented in Fig. 4. It reveals that out of 29 measures there are only 6 measures which are considered of high priority.

Phase 3. Multi-period and multi-objective formulation of the PROMETHEE V and its solution using the augmented \( \varepsilon \)-constraint (AUGMECON) algorithm

Step 7. Aggregate the initial fuzzy evaluation matrices. Aggregate the initial evaluation matrices of the \( K \) decision-makers using the arithmetic aggregation shown in (16) and the resulting aggregate evaluation matrix is represented as \( \tilde{G} = \left( \tilde{g}_{ij}(a_i) \right) \), where \( \tilde{g}_{ij}(a_i) = \left( m_{ij}, a_{ij}, \beta_{ij} \right) \).

Step 8. Calculate the fuzzy preference degrees \( \pi'(x, y) \) for all measures. First, compute the fuzzy deviation between a measure \( a_i \) and a limiting profile \( l_p \) using (17) and then calculate the fuzzy preference function using (18). The fuzzy preference degrees are then computed through (19).

Step 9. Defuzzify each preference degree using the Yager [92] operator. To transform \( \pi'(x, y) \) into its corresponding crisp value, the Yager [92] operator is utilized as defined in (20).

Step 10. Compute \( Q_i^+(x) \) and \( Q_i^-(x) \) and the net flow \( Q_i^0(x) \) of each measure. Determine the positive and negative flows of each measure using (21) and (22), respectively. Then, the net flows of each measure are determined through (23).

Step 11. Assign each measure to a class. In assigning each measure to a predetermined class, the assignment rule based on the net flow as defined in (26) is used. The sorting results are presented in Fig. 4. It reveals that out of 29 measures there are only 6 measures which are considered of high priority.

Step 12. Formulate the multi-objective extension of the PROMETHEE V. PROMETHEE V is an extension proposed by Brans and Mareschal [18] to deal with optimization problems that select a subset of alternatives given a set of constraints (e.g., resources). While the PROMETHEE V is a 0-1 optimization model, we explore a case when decision variables denote the degree of implementation of the alternatives scaled in a closed interval \([0, 1]\) in a multi-period environment. In addition, due to the vagueness and uncertainty associated with the evaluation matrix in Step 6, we extend such a problem to a fuzzy environment; thus, promoting a multi-period multi-objective extension of the PROMETHEE.
V under fuzzy conditions. As in the original formulation of the PROMETHEE V which requires the outranking flows \((\phi^+, \phi^-)\), in this work, these flows are obtained from a fuzzy PROMETHEE extension proposed by Geldermann et al. [95] with the adoption of the Yager [92] index. For brevity, the steps are not provided here. Nevertheless, Table V presents the values of \(\phi^+, \phi^-, \phi_t\).

Table V. Outranking flows obtained through fuzzy PROMETHEE

| Measures | \(\phi^+_i\) | \(\phi^-_i\) | \(\phi_t\) |
|----------|-------------|-------------|-------------|
| M1       | 0.29        | 0.08        | 0.2143      |
| M2       | 0.22        | 0.10        | 0.1218      |
| M3       | 0.34        | 0.05        | 0.2861      |
| M4       | 0.25        | 0.16        | 0.0894      |
| M5       | 0.22        | 0.16        | 0.0505      |
| M6       | 0.06        | 0.43        | -0.3621     |
| M7       | 0.07        | 0.48        | -0.4036     |
| M8       | 0.05        | 0.50        | -0.4520     |
| M9       | 0.20        | 0.14        | 0.0600      |
| M10      | 0.21        | 0.12        | 0.0908      |
| M11      | 0.13        | 0.24        | -0.1133     |
| M12      | 0.19        | 0.15        | 0.0391      |
| M13      | 0.10        | 0.25        | -0.1441     |
| M14      | 0.13        | 0.19        | -0.0583     |
| M15      | 0.17        | 0.16        | 0.0193      |
| M16      | 0.13        | 0.18        | -0.0486     |
| M17      | 0.20        | 0.14        | 0.0624      |
| M18      | 0.16        | 0.18        | -0.0163     |
| M19      | 0.21        | 0.11        | 0.0965      |
| M20      | 0.19        | 0.10        | 0.0881      |
| M21      | 0.14        | 0.17        | -0.0372     |
| M22      | 0.31        | 0.07        | 0.2407      |
| M23      | 0.20        | 0.11        | 0.0891      |
| M24      | 0.12        | 0.20        | -0.0779     |
| M25      | 0.15        | 0.14        | 0.0081      |
| M26      | 0.18        | 0.16        | 0.0115      |
| M27      | 0.25        | 0.08        | 0.1683      |
| M28      | 0.15        | 0.21        | -0.0650     |
| M29      | 0.20        | 0.15        | 0.0423      |

The following formulates the proposed optimization model.

Indices
- \(i, j\) denotes a measure
- \(t\) denotes an implementation period
- \(p\) denotes a constraint

Parameters
- \(\phi^+_i, \phi^-_i\) are, respectively, the net, positive, and negative outranking flows of the \(i\)th measure previously obtained using the F-PROMETHEE methodology.
- \(\varphi_{p,i}\) is the coefficient associated with the \(p\)th constraint and the \(i\)th measure. \(p, i = 1, i\) and \(p, i = 2, i\) represent the total capital and manhour requirements to fully implement the \(i\)th measure, respectively.

\(\psi_p\) is the annual budget associated with the \(p\)th constraint.
\(\gamma_t\) is the minimum annual degree of implementation of the \(t\)th measure in addressing the \(t\)th barrier.

Decision variables
- \(x_{i,t}\) is the degree of implementation of the \(i\)th measure at the \(t\)th period.

The general formulation of the PROMETHEE V is presented in Model found in (27).

\[
\begin{align*}
\max & (\sum_i \varphi_i x_i) \\
\text{s.t.} & \sum_i \varphi_{p,i} x_i \leq \psi_p, \forall p \\
& x_i \in \{0, 1\}, \forall i
\end{align*}
\]

(27)

The \(\sim\) symbol denotes \(>, <,\) or \(=\) relationship. PROMETHEE V maximizes the net outranking flow previously obtained using the PROMETHEE process by selecting the best alternatives from a set of alternatives in a \([0,1]\) optimization environment. The number of selected alternatives depends on the parameters \(\varphi_{p,i}\) and \(\psi_p\). A solution to PROMETHEE V is guaranteed to optimality because it is a straightforward binary linear mathematical program. However, it has several characteristics that warrants some attention. First, the selection of alternatives do not provide information on priority, which is crucial in decision-making. Second, the model is static and provides limited support in planning programs of temporal nature. Lastly, the value of \(\phi_t\) is ambiguous in the sense that it can either be negative or positive. This is consequent to the fact that \(\phi_t\) is an aggregate of two competing values, namely \(\phi^+_t\) and \(\phi^-_t\).

In a practical sense, \(\phi^+_t\) can be interpreted as the composite value indicating the degree in which alternative \(i\) outperforms other alternatives, while \(\phi^-_t\) indicates the degree in which alternative \(i\) is outperformed by others. It is apparent that a rational decision-maker would prefer a measure that maximizes \(\phi^+_t\), but minimizes \(\phi^-_t\). In a way, maximizing \(\phi_t = \phi^+_t - \phi^-_t\) is equivalent to the simultaneous optimization of \(\phi^+_t\) and \(\phi^-_t\). However, such a claim is only true if one is not preferred over the other. For instance, \(\phi^+_t\) maybe a characteristic of an alternative that is more preferred than \(\phi^-_t\) and vice versa. Exclusively maximizing \(\phi_t\) do not account for this preference, which clearly affects the solution of the decision-making problem. To address these concerns, the canonical PROMETHEE V model is extended here as a multi-period and multi-objective linear program (MOLP) referred to from here on out as PROMETHEE-MOLP. The PROMETHEE-MOLP is formulated in the model in (28).

\[
\begin{align*}
\max & (\sum_{t,i} \varphi^+_i x_{i,t}) \\
\min & (\sum_{t,i} \varphi^-_i x_{i,t}) \\
\text{s.t.} & \sum_{i} \varphi_{p,i} x_{i,t} \leq \psi_p, \forall (p,t) \\
& \sum_t x_{i,t} \geq \gamma_i, \forall (i,t)
\end{align*}
\]

(28)
The model in (28) is formulated to address the dynamic resource allocation problem concerning the implementation of measures for addressing several UTT barriers. The objective functions are the maximization of the positive outranking flow and the minimization of the negative outranking flow. In this particular problem, the former objective is more preferred than the latter because it is a more direct indicator of performance. This preference will be incorporated in the solution scheme adopted here that will be considered later. The constraint $\sum_i \varphi p_i x_{1,t} \leq \psi p, \forall (p, t)$ is the multi-period version of the constraint in the canonical PROMETHEE V model. In this formulation, $x_{1,t}$ is defined in $[y_1, 1]$ and may assume a rational value. The bounds of the values of $x_{1,t}$ are implicit through the constraints $\sum_i x_{1,t} \leq 1$ and $x_{1,t} \geq y_1$. This feature addresses the concern on the lack of prioritization information in the PROMETHEE V model. A large value of $x_{1,t}$ indicates that measure $i$ is prioritized at period $t$.

**Step 13.** Implement the AUGMECON algorithm to solve the proposed PROMETHEE-MOLP. In this paper, the solution of the model in (28) is obtained using the Mavrovou's [91] augmented $\varepsilon$-constrained algorithm for multi-objective mathematical programming which more commonly known in the literature as the AUGMECON algorithm. The classical $\varepsilon$-constrained algorithm of Haimes et al. [97] do not guarantee the efficiency of solutions. The AUGMECON was developed to address this crucial issue by providing an alternative process to obtain the payoff matrix in such a way that the range of the objectives is obtained lexicographically. The lexicographic optimization variable this is provided by Ma et al. [91] which has low priority. The slack variable $\varepsilon_1$ is a small arbitrarily number, and $\varepsilon_2 r_i$ is the direction of the priority objective denoted by $f_i(x_1, x_2, ...), (x_1, x_2, ...)$ $\in S$, where $S$ is the set of all feasible solutions. The value of $\varepsilon_2 r_i$ is $-1$ if the $i$th objective function is to be minimized, otherwise, $+1$. Obviously, the second term of the objective function has low priority. The slack variable $\varepsilon_1 \geq 0$ forces the linear program to produce only efficient solutions. A proof of this is provided by Mavrovou [91]. On the other hand, the variable $\gamma_i = \max f_i - \min f_i$ represents the range of the $i$th objective. The range is obtained from the payoff table which is obtained lexicographically. The lexicographic optimization for obtaining the payoff table whose elements are guaranteed efficient is as follows: the objective function with higher priority is optimized to obtain $f_1 = z_1^*$. Then the second objective function is optimized by adding the constraint $f_1 = z_1^*$ to obtain $f_2 = z_2^*$. Subsequently, the third objective function is optimized by adding the constraints $f_1 = z_1^*$ and $f_2 = z_2^*$ in order to keep the previous optimal solutions and so on, then all objective functions are assessed. The range $\gamma_i$ of the objective functions are obtainable after this step. Then, the number of grid points $q$ must be decided. The efficient solutions of the model in (29) are obtained by varying the value of $\varepsilon_1$ parametrically. The value of $\varepsilon_1$ is varied $q$ number of times using the following formula:

$$
e_1(k) = e_1(k-1) + \frac{\max f_i - \min f_i}{q-1}, k = 2, 3, ..., q; e_1(1) = \min f_i$$  \hspace{1cm} (30)$$

The counter $k$ corresponds to each iteration. In this study, $e_1$ is varied $q = 100$ number of times.

**Step 14.** Determine the Pareto optimal solutions. Each of the 100 Pareto optimal and efficient points that are obtained through this process are alternative solutions. One of the advantage of the MOLP formulation of the PROMETHEE V is that it permits a more interactive selection of potential many solutions, which is not possible given the canonical model. In this study, manual evaluation of 100 alternatives solution could burden the decision-makers, so an alternative approach is adopted. This study adopts the proposed selection procedure of Du et al. [93] which makes use of fuzzy set theory to assign membership degrees to candidates solutions. The linear membership function is defined in (31).

$$
\sigma_i^r = \begin{cases} 
\frac{\max f_i - f_i^r}{\max f_i - \min f_i} \Rightarrow \text{objective } i \text{ is minimized} \\
\frac{\min f_i - f_i^r}{\max f_i - \min f_i} \Rightarrow \text{objective } i \text{ is maximized}
\end{cases}
$$  \hspace{1cm} (31)

The variables $f_i^r$ and $\sigma_i^r$ represent the value of the $i$th objective function and its membership function in the $r$th Pareto optimal solution, respectively. The membership function $\sigma_i^r$ indicates the degree of optimality for the $i$th objective function in the $r$th Pareto optimal solution. The overall degree of optimality of each Pareto optimal solution is computed considering their membership function and the relative importance of the objectives using Equation (32).

$$
\sigma^r = \sum_i w_i \sigma_i^r
$$  \hspace{1cm} (32)

The most preferred solution refers to the Pareto optimal solution with the highest value of $\sigma^r$ or the highest aggregate preference for the multi-objective problem. In this work, only two objective functions are considered, which correspond to the positive outranking flow and the negative outranking flow, namely: $f_1 = \sum t \phi^+ x_{1,t}$ and $f_2 = \sum t \phi^- x_{1,t}$.

**V. SENSITIVITY ANALYSIS**

A layer of sensitivity analyses is performed to assess the extent of the results sensitivity with changes in the values of important parameters and changes in the method used for computing these values. The first analysis examines the results of the MCS problem. In this analysis, the F-FlowSort and
FlowSort are solved for the baseline values of the preference functions. It serves as the first scenario (scenario BASELINE). The second scenario assumes that the preference functions of all UTT barriers are classified as U-shape (scenario ALL2). The third and last scenario assumes that the preference functions are classified as V-shape (scenario ALL3). This analysis is performed because identifying the preference function type is among those procedures that experts usually find difficult. This analysis aims to investigate whether results vary significantly with an ample change in the classification of the preference functions. The results are summarized in Fig. 4. It reveals that the treatment does not significantly affect the results. Despite the perturbations introduced in the test to perturb the results, the sorting outcomes generally remained the same. The resulting six scenarios from the test also show extremely correlated results, as shown in Table VI.

The effect of the sensitivity of the best scenarios on the multi-objective problem is also investigated. Fig. 5 shows the shifting of the Pareto frontier consequent to the sensitivity scenarios. Interestingly, while the Pareto optimal solutions seem to be sensitive to the induced changes, the resulting extent of implementation of the measures is unaffected, as shown in Fig. 6. This observation is crucial since it entails that very small perturbations to the degree of implementation of the measures result in drastic shifts in the optimal objective values. Thus, selecting the preference function type in the sorting problem and the fuzzy PROMETHEE process must be carried out with profound attention.

In this analysis, the results of the AUGMECON are also compared to the canonical $\varepsilon$-constraint algorithm of Haimes [97]. The comparison shows that the results of the AUGMECON and the canonical $\varepsilon$-constraint algorithm are exactly the same. This is explained by the nature of the optimization problem involved in this work which represents an ordinary LP model with continuous decision variables, which guarantees solution uniqueness. In cases where the solution of the LP is unique, the AUGMECON and the canonical $\varepsilon$-constraint algorithm yield exactly the same solutions. On the computation complexity of the AUGMECON against the canonical $\varepsilon$-constraint algorithm, Mavrotas [91] provided a thorough discussion on the advantage of the AUGMECON.
A comparison of the solution of PROMETHEE-MOLP and the PROMETHEE V approach is presented in Table VI. Pearson correlation matrix*.

The last test carried out in this section aims to compare the results of the PROMETHEE-MOLP with that of the canonical PROMETHEE V. To this end, the model in (28) is solved with the following objective function that maximizes the net outranking flow:

$$\max \left( \sum_{l,t} \phi_i x_{i,l,t} \right), \text{s. t. constraints in Model } (28) \quad (33)$$

A comparison of the solution of PROMETHEE-MOLP that is obtained using the AUGMECON algorithm and the solution selection process of Du et al. [98] described previously, assuming $w_1 = w_2 = 0.5$, and the result of the model in Equation (33), also labeled as DYNAMIC PROMETHEE V, is presented in Fig. 7. The average implementation of the measures with the DYNAMIC PROMETHEE V approach is 72.08%, while the PROMETHEE-MOLP obtained only 60%.

Clearly, the former approach is much more effective in this metric. In terms of computational expense, the latter approach requires a solution to a manifold of optimization subproblems while the former requires only one. Also, considering that $\max \left( \sum_{l,t} \phi_i x_{i,l,t} \right) = \max \left( \sum_{l,t} \left( \phi_i^+ - \phi_i^- \right) x_{i,l,t} \right) = \max \left( \sum_{l,t} \phi_i^+ x_{i,l,t} \right) - \min \left( \sum_{l,t} \phi_i^- x_{i,l,t} \right)$ then the net outranking flow of the two approaches can be directly compared since $\max \left( \sum_{l,t} \phi_i x_{i,l,t} \right)$ corresponds to the objective of the DYNAMIC PROMETHEE V while $\max \left( \sum_{l,t} \phi_i^+ x_{i,l,t} \right)$ and $\min \left( \sum_{l,t} \phi_i^- x_{i,l,t} \right)$ correspond to the objective of the PROMETHEE-MOLP. The obtained net outranking flow using DYNAMIC PROMETHEE V is 0.7671, while PROMETHEE-MOLP is 0.6926. Based on these multiple comparisons, in this particular case, the DYNAMIC PROMETHEE V is obviously the more suitable method to use over the proposed PROMETHEE-MOLP. However, we highlight that the DYNAMIC PROMETHEE V fails to consider the effect of negative outranking flows – a loss of crucial information on the behavior of the alternatives (i.e., UTT measures). The decision-maker is left with a choice to consider the two formulations considering a balance of risk and computational efficiency.

VI. RESULTS AND DISCUSSIONS

In this study, various measures are developed to address the 24 UTT barriers first identified by Quiñones et al. [8], with subsequent analysis on their inherent interdependencies (see [11]). This agenda is a direct consequence in strategic planning, where priority measures are designed and implemented to overcome the barriers of UTT process. To identify those priority barriers, we consider an MCS problem, where measures are considered alternatives under the evaluation of 24 barriers. With the agenda of prioritizing the measures in addressing the identified UTT barriers, the proposed integration of fuzzy DANP and F-FlowSort is implemented in an actual case study of a university. Finally, the allocation of resources for implementing the priority measures is demonstrated as a multi-period planning problem using the proposed multi-objective extension of the PROMETHEE V under a fuzzy environment.

As shown in Fig. 3, results revealed that out of 29 measures, only six measures are sorted in the “high priority” class. These are designing a sustained partnership built on the principle of equal rights, reciprocity, and mutual advantage (M1), engaging in joint research ventures by encouraging more partners (e.g., industry, R&D institutions, and funding institutions) to be involved in the projects (M3), establishing...
partnerships from international financial institutions for bilateral fund resources to support the high costs of research projects (M19), streamlining objectives to full support of the technology readiness levels from ideation to full commercial application (M22), establishing a holistic system approach towards technology readiness levels (M23), and establishing agreements with industry partners to have access to the industry laboratory facilities (M27). A sustained relationship with partners (M1) promotes trust and experience for further participating in collaborative discussions among present and future partners and engaging in long-term university-industry linkages. Striving to share a long-term collaboration is tantamount to elevating strong connections in exchange for mutual gains. Moreover, this would create a better interpersonal recognition for those willing to engage in UI linkages.

On the other hand, the university is urged to engage in more joint research ventures with extra partners from academia, industry, and financial institutions (M3). It intends to streamline IP commercialization processes and support other high priority measures, such as M19, M22, and M23. Considered as a long-term for establishing a university entrepreneurial culture for value creation that impacts UTT performance [59], actively promoting multisectoral research projects which would produce impactful IP assets must be part of the strategic directions of the case university. Since cost remains a significant barrier in UTT, measure M19 is given high priority to sustain the agenda of collaborating partners towards internationally recognized innovations. Seeking the support of international funding institutions not only directly augment project costs but also uplifts the image of partners and compels them to produce tangible IP assets with greater societal impact. On the other hand, high priority measures M22 and M23 are closely linked. Having a well-established technology readiness levels program would become an essential platform for developing technologies in IP protection and commercialization. For instance, Cabrera et al. [93] claimed that those technologies with a lower level of technology readiness most likely require more R&D attention than those with higher levels. Finally, access to industry laboratory facilities (M27) augments the gap between the resources available within the university and the required facilities to achieve desirable R&D results. In the case of universities situated in a developing economy, the technological resources of universities to support R&D are significantly lesser than those in the industry. Thus, providing university innovators with the much-needed laboratory support is likely available in the industry would encourage more innovations for UTT. Moreover, as pointed out by scholars [74], [76], universities need industry experts in identifying and managing the commercial value of R&D outputs, which is a critical aspect of UTT.

Finally, through the proposed PROMETHEE-MOLP, universities would be provided a decision support platform for resource allocation in successfully implementing the priority UTT measures. In addition, the proposed methodological resource planning framework offers a platform for capturing imprecision and uncertainty in group decision-making, often relevant to avoid counterintuitive solutions. The flexibility inherent in the Pareto optimal solutions offers decision-makers a range of options in planning for implementing priority measures while taking into account some idiosyncrasies. For instance, the plan offered in Fig. 7 (PROMETHEE-MOLP) provides inputs to university management in allocating needed resources and all necessary support in implementing these measures. It must be noted that the degree to which a measure \( t \) to be implemented in period \( t \), denoted as \( x_{it} \), in the closed interval \([0,1]\) implies a feature related to the proportionate number of activities required to fully implement a given measure. Lastly, the layer of sensitivity analysis provided in this work offers insights into the robustness of the proposed methodological platform due to changes in the model parameters. The analysis suggests that while the preference function types in the F-FlowSort has minimal impact on the sorting process, it induces significant changes in the multi-period planning problem.

VII. MANAGERIAL AND POLICY INSIGHTS

The findings of this work provide a better understanding of planning the implementation of high priority measures that significantly address a range of UTT barriers. As such, this approach provides vital insights into decision-makers’ strategic actions, plans, and resource allocation decisions. Moreover, UTT measures can be prioritized through strategic initiatives and appropriately allocate funds for a specified planning horizon. The overarching results of this work can be used to leverage the university to recommend possible pathways on how to efficiently and effectively implement the high priority measures. In this section, these measures are highlighted to generate insights to inform the design of policies.

One of the high priority measures is designing a sustained partnership built on the principle of equal rights, reciprocity, and mutual advantage. As perceived by experts, this measure shows a high degree of capability in addressing barriers such as the lack of appropriate partners and lack of recognition for UI linkages. Developing a long-term collaboration is significant because it leverages the network of connections to exchange valuable resources, achieved through a concerted effort of parties to accelerate development and significantly contribute to emerging academic entrepreneurship. For instance, the parties participating in academic entrepreneurship are entitled to a reasonable share of the profits based on the terms and conditions agreed by these parties. This task addresses key partnerships outcomes and has a ripple influence on other UTT barriers because it brings together blended knowledge and technology, a part of more extensive collaboration.

Other high priority measures are (1) engaging in joint ventures by encouraging more partners to be involved in the projects, (2) establishing partnerships from international financial institutions for bilateral fund resources to support the high costs of research projects, and (3) forming agreements with industry partners to have access to the industry laboratory.
facilities. Universities are compelled to contribute to socioeconomic development through technology transfer. According to Amry et al. [99], UTT initiatives contribute to the commercialization of IP assets. In this context, the university is expected to expand its engagement in collaborative research ventures involving additional partners from academia, industry, financial institutions, among others, as this collaboration would accelerate IP commercialization. For example, financial institutions and enterprises may establish a shared service facility within the university premises so that researchers, innovators, and students can access the shared laboratory to complete their projects efficiently. Similarly, a possible approach to these measures is to form fellowships and alliances, in which the university engages in a contract agreement with national and international R&D institutions with corresponding responsibilities and deliverables. Consistent with the insights of Quinones et al. [11], the government should increase its efforts to launch calls for financial grants as subsidies for universities to fund UTT activities. Another potential direction is to raise R&D expectations by building a solid university image, increasing university exposure to the academic and scientific community, amplifying networks, attracting investors, and entering into joint ventures with viable performance indicators.

The further two high priority driving measures are streamlining objectives to fully support the technology readiness levels from ideation to complete the commercial application and establishing a holistic system approach towards these levels. These measures address eight specified barriers with a moderate to high effect capacity. According to Vining and Lips [100], Dutch universities failed to successfully transfer and commercialize their high research outputs. One possible course of action is to use technology readiness levels as an instrument to verify the project’s potential success for IP protection and commercialization. For instance, during an IP audit, technology readiness levels can determine the commerciality of IPs, allowing the institution to prioritize technologies with high commercial potential. In addition, innovators would be assisted in doing R&D initiatives that will result in innovation, ensuring that knowledge is transformed into wealth creation.

VIII. CONCLUSION AND FUTURE WORK

Technology transfer plays a crucial role in translating knowledge into assets for advancing the economy and society. In particular, UTT has been gaining interest due to the vast potential of universities for generating and commercializing IP assets. Due to its complexity, various barriers to its successful implementation were identified in the literature. However, holistically addressing these barriers to provide universities pathways of advancing UTT remains a gap. Thus, this work contributes to the literature by developing an integrated methodological framework that systematically identifies high priority measures to overcome UTT barriers and subsequently allocates resources to implement these measures in a specified planning horizon optimally. The overall framework is augmented by incorporating fuzzy set theory to handle vagueness and uncertainty, especially decision-making. In the proposed framework, the fuzzy DANP assigns weights of the UTT barriers, while the F-FlowSort classifies the measures according to their degree in addressing the barriers. Implementing these measures is carried out by a proposed multi-objective extension of the PROMETHEE V. From the 24 identified UTT barriers previously reported, along with their interdependencies via fuzzy DEMATEL, the proposed methodology is demonstrated in an actual case study in a Philippine public university.

Findings suggest that out of the 29 possible measures for UTT barriers, the following measures are identified as high priority:

- designing a sustained partnership built on the principle of equal rights, reciprocity, and mutual advantage
- engaging in joint research ventures by encouraging more partners (e.g., industry, R&D institutions, and funding institutions) to be involved in the projects
- establishing partnerships from international financial institutions for bilateral fund resources to support the high costs of research projects
- streamlining objectives to full support of the technology readiness levels from ideation to full commercial application
- establishing a holistic system approach towards technology readiness levels
- establishing agreements with industry partners to have access to the industry laboratory facilities

Out of these priority measures, strategic initiatives were offered as necessary actions for the implementation. Among these initiatives are (1) recognizing the equal distribution of expenses and shared through a legal agreement between the collaborators, (2) establishing a shared service facility in a university that researchers, students, and faculty can utilize, (3) initiating fellowships and alliances with national and international R&D institutions, (4) building a robust university profile to attract collaborators and investors, and (5) supporting technology readiness levels from ideation to commercialization through a holistic, systematic approach. After identifying the high priority measures, an extended PROMETHEE-MOLP was conducted to provide an optimal implementation of these measures subject to the allocation of resources (i.e., financial, manpower). Layers of sensitivity analysis were implemented to evaluate the results brought about by changes in the model parameters.

These findings are beneficial for the decision-makers in institutions implementing UTT initiatives organizations. Moreover, the prioritization of the measures and their optimal implementation can also aid in designing a strategic management plan for advancing UTT. Although these insights contain idiosyncrasies, they can become starting points of discussions in the literature. Despite its advances, certain limitations exist for this study. Since the case environment of this study is a public university, certain results may only be limited to public HEIs. Moreover, the UTT barriers and the
measures identified to address them may not be a comprehensible list that is applicable to all organizations. As a future research agenda, the proposed methodology could be applied to other case environments with a different set of UTT barriers and measures. Other MCS methods such as PROMSORT, ELECTRE-SORT, ELECTRE-TRI, among others, under other fuzzy environments (e.g., intuitionistic fuzzy sets, neutrosophic sets, rough sets) can also be utilized.

APPENDICES

Appendix A. Types of generalized criteria [15].

| Generalized criterion | Definition |
|-----------------------|------------|
| Type I: Jausal Criterion | \[ P(d) = \begin{cases} 0 & d \leq 0 \\ 1 & d > 0 \end{cases} \] |
| Type II: U-shape Criterion | \[ P(d) = \begin{cases} 0 & d \leq q \\ 1 & d > q \end{cases} \] |
| Type III: V-shape Criterion | \[ P(d) = \begin{cases} 0 & d \leq 0 \\ \frac{d}{p} & 0 \leq d \leq p \\ 1 & d > p \end{cases} \] |
| Type IV: Level Criterion | \[ P(d) = \begin{cases} 0 & d \leq q \\ \frac{q}{d} & q < d \leq p \\ 1 & d > p \end{cases} \] |
| Type V: V-shape with indifference Criterion | \[ P(d) = \begin{cases} 0 & d \leq q \\ \frac{d - q}{p - q} & q < d \leq p \\ 1 & d > p \end{cases} \] |
| Type VI: Gaussian Criterion | \[ P(d) = \begin{cases} 0 & d \leq 0 \\ 1 - e^{-\frac{d^2}{2\sigma^2}} & d > 0 \end{cases} \] |

Appendix B. List of UTT barriers (adopted from [8])

| Code | Barrier |
|------|---------|
| B1   | Lack of appropriate partners |
| B2   | Time constraints |
| B3   | Lack of resources |
| B4   | Risk of information leakage |
| B5   | Knowledge being too theoretical for practical purposes |
| B6   | Insufficient rewards for university researchers |
| B7   | Poor marketing/technical/negotiation skills of Technology Transfer Office (TTO) |
| B8   | University proponents have unrealistic expectations regarding the value of their technologies |
| B9   | Lack of recognition for university-industry linkages |
| B10  | Inconsistent rules and regulations |
| B11  | Lack of venture capital |
| B12  | High costs of managing joint research projects in terms of time and money |
| B13  | Cultural differences between academia and enterprises |
| B14  | Misalignment between research and commercialization objectives |
| B15  | Complex organizational structure |
| B16  | Institutional bureaucracy |
| B17  | Lack of personal motivation |
| B18  | Process complexity |
| B19  | Geographic distance |
| B20  | Lack of national benchmark to evaluate successful collaboration |
| B21  | Prototype technology not compatible with the demands of mass production |
| B22  | Problems concerning intellectual property rights |
| B23  | Procurement process |
| B24  | Lack of sales distribution centers within university premises |

Appendix C. Total relation matrix (adopted from [11])

|       | B1  | B2  | B3  | B4  |
|-------|-----|-----|-----|-----|
| B1    | 0.51423 | 0.54797 | 0.55871 | 0.51997 |
| B2    | 0.53449 | 0.49885 | 0.53882 | 0.51034 |
| B3    | 0.57067 | 0.56154 | 0.53597 | 0.54271 |
| B4    | 0.54757 | 0.54712 | 0.55217 | 0.49079 |
| B5    | 0.54750 | 0.54425 | 0.55030 | 0.52547 |
| B6    | 0.52220 | 0.51934 | 0.52481 | 0.49934 |
| B7    | 0.55626 | 0.55338 | 0.55844 | 0.52746 |
| B8    | 0.53102 | 0.52623 | 0.53474 | 0.50920 |
| B9    | 0.55055 | 0.54500 | 0.55376 | 0.52610 |
| B10   | 0.56243 | 0.55961 | 0.56647 | 0.54030 |
| B11   | 0.55745 | 0.55599 | 0.56382 | 0.53468 |
| B12   | 0.55501 | 0.55136 | 0.56086 | 0.53205 |
| B13   | 0.54321 | 0.53752 | 0.54759 | 0.51674 |
| B14   | 0.54709 | 0.54536 | 0.55470 | 0.52323 |
| B15   | 0.51736 | 0.51558 | 0.52410 | 0.49717 |
| B16   | 0.52961 | 0.52917 | 0.53621 | 0.50861 |
| B17   | 0.55488 | 0.55185 | 0.55843 | 0.52910 |
| B18   | 0.55084 | 0.55086 | 0.56031 | 0.52833 |
| B19   | 0.51821 | 0.51538 | 0.52545 | 0.49424 |
Appendix D. Measures in overcoming the barriers of university technology transfer

| Codes | Measures |
|-------|----------|
| M1    | Designing a sustained partnership built on the principle of equal rights, reciprocity, and mutual advantage. |
| M2    | Forging initiatives towards sponsored research engagements |
| M3    | Engaging in joint research ventures by encouraging more partners (e.g., industry, R&D institutions, and funding institutions) to be involved in the projects |
| M4    | Allowing more funds for promoting university technology transfer activities |
| M5    | Allowing more funds to hire talents (i.e., human resources) to conduct R&D tasks and navigate university technology transfer skills |
| M6    | Designing security measures that only trusted parties can have access to sensitive data and information |
| M7    | Incorporating non-disclosure agreement or data privacy protection among the identified personnel who have access to data and information |
| M8    | Investing endpoint protection against information leakage (e.g. phishing, Trojans, malware, among others) |
| M9    | Engaging in activities towards the completion of technology readiness levels |
| M10   | Creating technologies with tangible value to potential partners |
| M11   | Designing an incentive plan and reward system for personnel involved in R&D and university technology transfer activities |
| M12   | Putting the right people at the right job with a high sense of commitment |
| M13   | Forging change mindset of technology transfer officers from mere gatekeepers to acting as a bridge between university and industry |
| M14   | Designing initiatives for continuous professional development of the technology generators for sustaining the willingness to explore and learn |
| M15   | Developing a communication infrastructure to support proactive and efficient communication among parties involved in university technology transfer activities |
| M16   | Creating a platform of communication wherein industry partners will be appropriately recognized |
| M17   | Designing clear and consistent policies, with a message that entrepreneurial partnership would be of mutual benefit among various parties |
| M18   | Encouraging patents generation in the research works to have greater access to financial capital |

| Codes | Measures |
|-------|----------|
| M19   | Establishing partnerships from international financial institutions for bilateral fund resources to support the high costs of research projects. |
| M20   | Forging collaborative research agreements with fellow R&D institutions |
| M21   | Designing the integration of multiple functions (e.g., instruction, research, community extension, administration) of the university for technology transfer initiatives |
| M22   | Streamlining objectives to full support of the technology readiness levels from ideation to full commercial application |
| M23   | Establishing a holistic system approach towards technology readiness levels |
| M24   | Designing quantifiable metrics for technology transfer effectiveness |
| M25   | Allowing faculty-researchers to engage in spinoff activities |
| M26   | Establishing clear boundaries of intellectual property ownership, and its corresponding monetary benefits |
| M27   | Establishing agreements with industry partners to have access to the industry laboratory facilities |
| M28   | Expanding external distribution centers for a wider market audience. |
| M29   | Participating in exhibits, trade fairs, and forums to showcase university technology and attract potential investors |

SUPPLEMENTARY MATERIAL

The dataset can be accessed through https://drive.google.com/file/d/1D7zyhTMVCo4zNvLe-bSn1t8qyeNA1Ja9/view?usp=sharing.

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