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# Choosing the Best Private-Sector Partner According to the Risk Factors in Neutrosophic Environment

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## Abstract

Public-Private Partnership (PPP) refers to a partnership between a government and a private sector to provide public infrastructure projects, services, etc. These projects have been associated with numerous problems, many of which failed. A critical issue in PPP projects is choosing the right private-sector partner. Considering various criteria, the public sector has to select the best alternative concerning uncertainty. There needs to be a focus on well-structured, feasible decision approaches necessary to improve the performance of PPPs. In the MCDM context, the ratings of the alternatives provided by decision-makers can be expressed with the Fuzzy Set theory. Single-valued neutrosophic sets SVNSs are well suited for handling ambiguous, incomplete, and imprecise information. Moreover, some information measures for the SVNS model have been proposed, such as similarity measures. As selecting the suitable private-sector partner problem is an MCDM one, including various risk factors and uncertainty, this article has addressed choosing that by considering the risk factors as the problem criteria in a neutrosophic environment. We proposed a simple, practical approach to solve the problem of selecting the best private-sector partner. This approach considers the most critical risk factors affecting the infrastructure PPP project and copes with uncertainty using SVNSs.

**Keywords:** Public-private partnership, Neutrosophic sets, SVNS, Decision-making, Similarity measure.

## 1 | Introduction



Public-Private Partnership (PPP) has been widely recognized as an important and effective way to procure public works with less public financial input and more private participation [1]. A PPP refers to a partnership between the government and private investors to provide public infrastructure projects, public goods, and services [2]. PPP schemes generally refer to the public and private sectors' relationship with challenging responsibilities to deliver public services [3]. It has become increasingly popular to involve the private sector in developing public infrastructures [4], [5]. The prime objective of the public sector through the PPP model is to maintain the money value of the services rendered to the public while ensuring the efficiency and effectiveness of the private sector involved in the contractual relationship [6].

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Although the initial motive for implementing PPPs was found for financial needs [7], these projects have been associated with numerous problems, and many of them failed or required renegotiation [8]. PPP project failures are not rare, and the loss of a PPP is mainly due to PPP risks [2]. A project risk is an unknown event or situation that affects project objectives positively or negatively [9]. Most PPP projects encounter various risks because of the complexity and uncertainty of PPP projects [10]. Political risks, including the unstable policy, may directly determine whether the project can be approved for commencement or not. Besides, financial risks, such as inflation and interest rate changes, may increase unexpected costs and reduce incomes. Economic risks such as high costs of operation and maintenance can block the continuation of the project. What's more, technical risks, especially charging technology, inadequate interconnection, and technology payment risks, may decrease the charging infrastructure frequency, which directly results in the losses of the PPP project. Apart from these, the risks brought by the project and the project participant itself, such as the PPP experience, cannot be ignored [11].

A critical issue in PPP projects is selecting the right private-sector partner, which is a risky process. The selection of partners is often challenging and poses a significant risk for conflict and PPP relationship failures [7]. In such projects, host governments play essential roles in selecting suitable private sectors, accepting the responsibility to create an attractive investment climate, and adequately preparing projects to stimulate interest from private companies [12]. Considering various criteria, the public center has to select the best alternative concerning uncertainty. In the MCDM context, the ratings of the options provided by decision-makers can be expressed with the Fuzzy Set theory [13].

Fuzzy sets theory has been widely and successfully applied in many different areas to handle such uncertainty [14]. Nevertheless, it presents limitations to dealing with imprecise and vague information when various sources of vagueness appear simultaneously [15], [16]. Atanassov mentioned that there should be a degree of non-membership ($\nu$) in addition to membership function ($\mu$) in fuzzy sets [17]. Such sets are called Intuitionistic Fuzzy Sets (IFSs) [18]. IFSs can only handle incomplete information, not indeterminate and inconsistent information commonly in the belief system [19]. Duran et al. [16] germinated the notion of having a Neutrosophic Set (NS) holding three different fundamental elements: truth, indeterminate, and falsity [20], [43]. Each attribute of the NSs is relevant to our real-life models [21], [22]. The most exciting point is that all these three functions are entirely independent, and one function is not affected by another [23]. These NSs can handle indeterminate and inconsistent information quite well, whereas IFSs and FSs can only handle incomplete or partial information [24].

Since NSs are difficult to apply in real engineering problems and scientific applications, a subclass of NS has been proposed by Wang et al. [19]. These sets are called single-valued NSs [25]. SVNSs are well suited for handling ambiguous, incomplete, imprecise information [26]. Since its appearance and the ability to tackle the indeterminacy at the initial stage of data, SVNS is one of the hot topics to tackle the DMPs [27]. SVNS is one of the most favorable environments to access the alternatives [27]. Ratings of criteria of decision problems can be expressed using linguistic variables that can be transformed into SVNNs [28]. Moreover, many information measures for the SVNS model have been proposed over the years, such as similarity, distance, entropy, inclusion measures, and correlation coefficients [29]. Many scholars and researchers have continuously proposed new similarity measures for fuzzy-based models, including the SVNS model, and applied these measures to solve various practical problems related to MCDM [29]. In some real applications and related fields, the researcher uses similarity measure, an important mathematical tool [30].

As selecting the suitable private-sector partner problem is an MCDM one, including various risk factors and uncertainty, this article has addressed choosing that by considering the risk factors as the problem criteria in a neutrosophic environment. The rest of the article is arranged as follows: In Section 2, some preliminaries, including the NS, SVNS, and SM, are described. In Section 3, the proposed approach is presented in section 4, a numerical example is defined, and the results are presented. Finally, conclusions are drawn in Section 5.

## 2 | Preliminaries

In light of big data as a branch of information theory, it is essential to have a tool to manage the vulnerability and irregularity of information [28], [31]. SVNS is one of the hot topics to tackle real-life decision-making problems [27]. To compute SVNS in the application, this section provides the related definitions.

**Definition 2.1.** [32] let $X$ be a universe of discourse. A NS $A$ is an object having the farm $A=\left\{\left(x: T_{A(x)}, I_{A(x)}, F_{A(x)}\right), x\in X\right\}$ characterized by truth-membership function $T_{A(x)}$, indeterminacy-membership function $I_{A(x)}$, and falsity-membership function $F_{A(x)}$. These functions are real standard or nonstandard subsets of $]0^-, 1^+[$, with the condition $0^- \le T_{A(x)}+I_{A(x)}+F_{A(x)} \le 3^+$.

**Definition 2.2.** [19] let $X$ be a universe of discourse. The single-valued NS A is an object having the farm $A=\{(x: T_{A(x)}, I_{A(x)}, F_{A(x)}), x\in X\}$, where the functions are real standard subsets $[0,1]$, with the condition $0\le T_{A(x)}+I_{A(x)}+F_{A(x)}\le 3$.

For convenience, we can use $x=(T_A, I_A, F_A)$ to represent an element x in SVNS, and x is a single-valued neutrosophic number.

**Definition 2.3.** [33] let $A=\left\{x:\ T_{A(x)}, I_{A(x)}, F_{A(x)}\right\}$ and $B=\left\{x:\ T_{B(x)}, I_{B(x)}, F_{B(x)}\right\}$ be two single-valued NSs and S(A, B) be a similarity measure for SVNSs. S (A, B) satisfies the following properties:

I. $0\le S(A,B)\le 1$.

II. $S(A,B)=S(B,A)$.

III. $S(A,B)=1 \text{ if } A=B$.

IV. $S(A,B)\le S(A,C), \text{if}. A\le B\le C$.

**Definition 2.4.** [29] let $A=\left\{x:\ T_{A(x)}, I_{A(x)}, F_{A(x)}\right\}$ and $B=\left\{x:\ T_{B(x)}, I_{B(x)}, F_{B(x)}\right\}$ be two SVNSs. We can calculate S(A, B) applying *Eq. (1)* as follow:

$$S(A,B)=\frac{\sum x\in X(T_A^2(x)\cap T_B^2(x))+(1-I_A^2(x))\cap(1-I_B^2(x))+(1-F_A^2(x))\cap(1-F_B^2(x))}{\sum x\in X(T_A^2(x)\cup T_B^2(x))+(1-I_A^2(x))\cup(1-I_B^2(x))+(1-F_A^2(x))\cup(1-F_B^2(x))}. \quad (1)$$

## 3 | Methodology

This practical, straightforward method includes six steps as follows:

**Step 1.** Making a list of alternatives (final private-sector partners).

**Step 2.** Listing risk factors and choosing some of the most important ones.

**Step 3.** Defining the Ideal Alternative (IA) with the best performance in all the criteria, though there is no IA in the real world.

**Step 4.** Forming the decision-making matrix D by experts' opinions based on linguistic scale shown in *Table 1*.

**Table 1. Conversion of linguistic terms to the SVNSs [34].**

| Linguistic Terms | SVNSs |
|---|---|
| Excessive High (EH) | (1.00, 0.00, 0.00) |
| Very Very High (VVH) | (0.90, 0.10, 0.10) |
| Very High (VH) | (0.80, 0.15, 0.20) |
| High (H) | (0.70, 0.25, 0.30) |
| Medium High (MH) | (0.60, 0.35, 0.40) |
| Fair (F) | (0.50, 0.50, 0.50) |
| Medium Low (ML) | (0.40, 0.65, 0.60) |
| Low (L) | (0.30, 0.75, 0.70) |
| Very Low (VL) | (0.20, 0.85, 0.80) |
| Very Very Low (VVL) | (0.10, 0.90, 0.90) |
| Excessive Low (EL) | (0.00, 1.00, 1.00) |

**Step 5.** Calculating the similarity measure using *Eq. (1)*.

**Step 6.** Ranking the alternatives according to previous step results.

## 4 | Numerical Example

Roadways were first developed in the eighteenth century by the private sector in tollways and turnpikes. In the nineteenth century, the private sector was also involved in developing canals and railroads [7]. PPP concessionaire contracts have been extensively used in transportation infrastructure, e.g., airports, railways, urban mass transit, and roads [1]. PPP mode was widely adopted in highway infrastructure projects [10]. Here, by a numerical example, we will show how one can apply our approach to select the best private-sector partner. In the first step, consider five different alternatives ($A_1$, $A_2$, $A_3$, $A_4$, $A_5$), and the sixth one is IA. To choose the criteria (risk factors), we used factors shown in *Table 2*:

**Table 2. Risk of PPP infrastructure [11].**

| Risk Factors | Abbreviation |
|---|---|
| Cost of operation and maintenance | COM |
| Unreasonable layout | UL |
| Imperfect charging technology | ICT |
| Inadequate interconnection technology | IIT |
| Payment safety | PS |
| Insufficient operation income | IOI |
| Imperfect supervision of funds | ISF |
| Lack of experience in PPP | LEP |

According to *Tables 1* and *2*, the decision matrix D is available in *Table 3*. Now, applying *Eq. (1)*, we can compute the similarity measures as shown in *Table 4*.

The result shows that by considering the most important risk factors and using the similarity measure for SVNSs, $A_2$ is the most similar alternative to the ideal one.

**Table 3. The decision matrix.**

| D | COM | UL | ICT | IIT | PS | IOI | ISF | LEP |
|---|---|---|---|---|---|---|---|---|
| $A_1$ | (0.90, 0.10, 0.10) | (0.50, 0.50, 0.50) | (0.90, 0.10, 0.10) | (0.90, 0.10, 0.10) | (0.30, 0.75, 0.70) | (0.40, 0.65, 0.60) | (0.30, 0.75, 0.70) | (0.40, 0.65, 0.60) |
| $A_2$ | (0.70, 0.25, 0.30) | (0.90, 0.10, 0.10) | (0.60, 0.35, 0.40 | (0.50, 0.50, 0.50) | (0.50, 0.50, 0.50) | (0.50, 0.50, 0.50) | (0.60, 0.35, 0.40) | (0.80, 0.15, 0.20) |
| $A_3$ | (0.60, 0.35, 0.40) | (0.50, 0.50, 0.50) | (0.40, 0.65, 0.60) | (0.40, 0.65, 0.60) | (0.80, 0.15, 0.20) | (0.80, 0.15, 0.20) | (0.70, 0.25, 0.30) | (0.70, 0.25, 0.30) |
| $A_4$ | (0.70, 0.25, 0.30) | (0.60, 0.35, 0.40 | (0.70, 0.25, 0.30) | (0.80, 0.15, 0.20) | (0.50, 0.50, 0.50) | (0.70, 0.25, 0.30) | (0.60, 0.35, 0.40 | (0.30, 0.75, 0.70) |
| $A_5$ | (0.40, 0.65, 0.60) | (0.40, 0.65, 0.60) | (1.00, 0.00, 0.00) | (1.00, 0.00, 0.00) | (0.20, 0.85, 0.80) | (0.50, 0.50, 0.50) | (1.00, 0.00, 0.00) | (0.40, 0.65, 0.60) |
| IA | (1.00, 0.00, 0.00) | (1.00, 0.00, 0.00) | (1.00, 0.00, 0.00) | (1.00, 0.00, 0.00) | (1.00, 0.00, 0.00) | (1.00, 0.00, 0.00) | (1.00, 0.00, 0.00) | (1.00, 0.00, 0.00) |

**Table 4. Similarity measure.**

| S ($A_i$, IA) | Score | Rank |
|---|---|---|
| S ($A_1$, IA) | 0.623 | 5 |
| S ($A_2$, IA) | 0.713 | 1 |
| S ($A_3$, IA) | 0.684 | 3 |
| S ($A_4$, IA) | 0.689 | 2 |
| S ($A_5$, IA) | 0.648 | 4 |

## 5 | Conclusion

The public and private sectors are usually vulnerable and sensitive to change and face considerable challenges in transportation PPP projects [35]. The long-term nature of projects concluded with PPP contracts, the need for project profitability for the private sector, and the ongoing relationship between government agencies and the private sector have made these contracts very sensitive to environmental conditions [9]. There needs to be a focus on well-structured, feasible decision approaches necessary to improve the performance of PPPs [36]. The main problem is estimating and evaluating a set of alternatives in terms of criteria and conflicting targets [37], [38]. Referring to the PPP literature, we believe that the public sector can select the best private sector partner in a neutrosophic environment by using risk factors as criteria for a given problem. In real decision making, to choose the best alternative from all the feasible sets of other options [39], multi-criteria decision-making problems and solution methods are the essential branches of modern decision sciences to deal with incomplete, indeterminate, and inconsistent information [30]. The indeterministic part of uncertain data, introduced in NS theory, plays a vital role in making a proper decision that is impossible by intuitionistic fuzzy set theory [40]. By NS, we can better represent reality by considering all aspects of the decision-making process [41].

In this study, we proposed a simple, practical approach to address the problem of selecting the best private-sector partner. This approach considers the most important risk factors affecting the PPP project and copes with uncertainty by using SVNSs. We shall address the criteria interdependency for future study by applying ANP [32] or DEMATEL-based ANP [33]. Moreover, as hesitancy is the most common problem in decision-making, and single-valued neutrosophic hesitant fuzzy sets are more general and practical than existing decision-making methods [42], we will use them in our subsequent study.

## Conflicts of Interest

All co-authors have seen and agree with the manuscript's contents, and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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