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Research paper

Prioritizing factors affecting traffic volume of public-private partnership infrastructure projects

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Abstract

Public-private partnership (PPP) is an effective alternative for raising capital for infrastructure projects and has been a popular trend in de-veloping countries recently. A key factor that affects the success of PPP transportation projects is traffic demand because it directly influ-ences project revenue. Inaccurate traffic demand estimates may lead to financial difficulties for private partners. This paper applies fuzzy extended analytic method (FEAM) to prioritize critical factors that affect traffic volume of PPP infrastructure projects. The results benefit both public and private sectors for realizing key factors for the success of PPP infrastructure project implementation.

Keywords: *Fuzzy Logic; Fuzzy Extent Analysis Method; Infrastructure; Public-Private Partnership (PPP); Traffic Volume.*

1. Introduction

Infrastructure is the foundation for economic development and is critical for sustainable development in developing countries. It encompasses basic facilities, services, and installations that are necessary for society. Poored-conditioned and under-developed infrastructure may hinder the improvement of the nation's economy. Infrastructure development requires massive capital investment because public infrastructure projects are usually large, complex, and extremely risky. To address the shortage of capital, the private sector is invited to assist the government in financing infrastructure projects under the public-private partnership (PPP) scheme.

In PPP transportation projects, private companies typically encounter with various risks, one of which is traffic fluctuation. Since the primary source of their revenue is toll fees, traffic fluctuation will directly affect the revenue of PPP transportation projects. This may lead to financial difficulties for private concessionaires and prolong the concession period for a PPP project. Hence, it is inevitable to prioritize factors affecting traffic volume of PPP infrastructure.

Four main factors with 19 sub-factors affecting traffic volume of PPP projects were compiled from our literature review and were verified by five PPP transportation experts, as shown in Table 1. Among these factors, the "available free lanes" factor was removed from the list because the experts agreed that it is similar to the "project toll fee" factor and the "benefits and safety from using of facilities" factor. When free lanes are available, road users will consider whether to use the new service for their toll rates. It means that users consider its benefits, such as saving time or saving fuel. Based on these critical factors, a hierarchy model was developed, as shown in Figure 1. Table 2 displays the assessment scale used by the PPP experts.

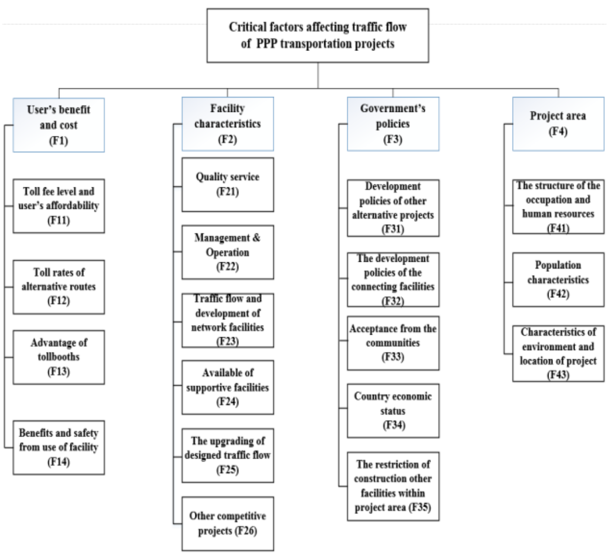

Fig. 1: Fuzzy Extended Analytic Method (Feam) for Prioritizing Factors Affecting Traffic Volume.

Table 1: Critical Factors Affecting Traffic Volume for PPP Transportation Projects

Code	Factors /Sub-factors	Source
F1	Benefits and costs of users	
F11	Level of project toll fee and the affordability of users	[1], [2], [3]
F12	Toll rates for alternative routes	[1]
F13	Advantage or disadvantage of the tollbooths	[4], [5]
F14	Benefits and safety for using facilities	[6]
F15	Available free lanes	[4], [5]
F2	Facility characteristics	

F21	Quality of project services and connecting networks	[1], [4]
F22	The management and operation of project unit	[7]
F23	The designed traffic volume and development of connecting facilities	[8]
F24	Available of supportive facilities	[3], [9]
F25	The upgrading of designed traffic volume	[8]
F26	Other competitive projects	[1], [10]
F3	Government's policies and social community	
F31	The development policies of other alternative projects, routes or traffic model	[11]
F32	The development policies of the connecting facilities	[11]
F33	Concurrence and acceptance from the communities with the project	[1]
F34	The economic status of the country or project area	[3], [12]
F35	The committed conditions from the government on the restriction of construction of other toll facilities within the project area	[1]
F4	Project area	
F41	The structure of the occupation and human resources of the project area	[13]
F42	The population characteristics in the project area	[2]
F43	Characteristics of environment and location of project	[1], [14]

Table 2: Linguistic Scales for Relative Importance

	Linguistic scale for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
1	Equal	(1, 1, 1)	(1, 1, 1)
2	Weak advantage	(1, 2, 3)	(1/3, 1/2, 1)
3	Not bad	(2, 3, 4)	(1/4, 1/3, 1/2)
4	Preferable	(3, 4, 5)	(1/5, 1/4, 1/3)
5	Good	(4, 5, 6)	(1/6, 1/5, 1/4)
6	Fairly good	(5, 6, 7)	(1/7, 1/6, 1/5)
7	Very good	(6, 7, 8)	(1/8, 1/7, 1/6)
8	Absolute	(7, 8, 9)	(1/9, 1/8, 1/7)
9	Perfect	(8, 9, 10)	(1/10, 1/9, 1/8)

2. Research methodology

Fuzzy analytical hierarchy process (FAHP) is a systematic tool for evaluating options. It combines the concepts of fuzzy theory and analytic hierarchy process (AHP) [15]. Experts are normally more confident to give interval opinions than fixed-value opinions because they are unable to explicitly indicate their preferences. This is primarily due to the fuzzy nature of the pairwise comparison method [16, 17]. In this paper, Chang's extent analysis method is applied because it is the simplest and efficient FAHP approach as compared to the other FAHP methods [18]. The steps of the fuzzy extended analytic method (FEAM) on the AHP approach are as follows [18-19]:

Let $X = \{x_1, x_2, . . ., x_n\}$ be an object set, and $U = \{u_1, u_2, . . ., u_m\}$ be a goal (objective) set.

Each object is taken and extent investigation for each goal (g_i) is conducted, respectively. Then, the m extent analysis values for each i^{th} object for m goals are obtained and shown as follows [20, 21]:

$$\tilde{M}_{g_i}^{j} \; (\tilde{M}_{g_i}^{1},\; \tilde{M}_{g_i}^{2}, \ldots,\; \tilde{M}_{g_i}^{m})$$

where $i = 1, 2,..., n$; $j = 1, 2,…, m$

All the $\tilde{M}_{g_i}^{j}$ are triangular fuzzy numbers (TFNs).

Step 1: Obtain priority weights

First, we apply fuzzy triangular numbers for pairwise comparison by fuzzy AHP scale. Then, we apply Chang's fuzzy extended analytic method (FEAM) method to derivd the priority weights. The value of fuzzy synthetic extent on the i^{th} object is represented as [22]:

$$S_i = \left(\sum_{i=1}^{m} l_i, \sum_{i=1}^{m} m_i, \sum_{i=1}^{m} u_i\right) \otimes \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right)$$

Step 2: Comparing degrees of possibility

The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as $V(M_2 \geq M_1)$ and can be equivalently expressed as follows [23]:

$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) = \mu_{M_2}(d)$$

$$= \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases}$$

Where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}.

To compare M_1 and M_2, we need both values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

Step 3: Obtaining the weight vector

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i $(i = 1,2,..., k)$ can be defined by [22]:

$V (M \geq M_1, M_2,..., M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } ... (M \geq M_k)] = \min V(M \geq M_i),\ i = 1, 2,..., k.$

Assume that

$$d'(A_i) = \min V(S_i \geq S_k)$$

For $k = 1, 2,…, n$; $k \neq i$.

Then, the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T$$

Where Ai ($i = 1,2,..., n$) are n elements.

Step 4: Calculate the normalized weight vector

Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), ..., d(A_n))^T$$

Where W is a nonfuzzy number.

Step 5. Ranking of the factors

After getting the weights of the factors, the ranking of all factors is determined.

3. Results and discussion

To demonstrate, we identify the weights of main factors with respect to the overall objective. First, the synthetic fuzzy pairwise comparison matrices of experts will be constructed as follows:

	F_1			F_2			F_3			F_4		
F_1	1	1	1	1.3797	1.7826	2.2369	1.7411	2.1411	2.4915	1.0592	1.5518	2.1689
F_2	0.4471	0.5610	0.7248	1	1	1	1.7411	2.4595	3.1037	1.8206	2.2679	2.9137
F_3	0.4014	0.4670	0.5743	0.3222	0.4066	0.5743	1	1	1	1.0845	1.7411	2.4595
F_4	0.4611	0.6444	0.9441	0.3432	0.4409	0.5493	0.4066	0.5743	0.9221	1	1	1

With the fuzzy scale in Table 2, the weights of main factors are determined by using FEAHP method. First, in Step 1, the normalized weight vector obtained from synthetic pairwise comparison matrices is:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} \tilde{M}_{g_i}^{j}\right]^{-1} = \left(\frac{1}{23.6631}, \frac{1}{19.0384}, \frac{1}{15.2077}\right)$$

When applying Equation (1), the values of fuzzy synthetic extent can be determined:

$\tilde{S}_{F_1} = (0.2189, 0.3401, 0.5193)$; $\tilde{S}_{F_2} = (0.2117, 0.3303, 0.5091)$

$\tilde{S}_{F_3}$ = (0.1187, 0.1899, 0.3030); $\tilde{S}_{F_4}$ = (0.0934, 0.1397, 0.2246)

Then, we calculate the degree of possibility:

$V(S_1 \geq S_2) = 1;\ V(S_1 \geq S_3) = 1;\ V(S_1 \geq S_4) = 1$

$V(S_2 \geq S_1) = 0.967;\ V(S_2 \geq S_3) = 1;\ V(S_2 \geq S_4) = 1$

$V(S_3 \geq S_1) = 0.359;\ V(S_3 \geq S_2) = 0.394;\ V(S_3 \geq S_4) = 1$

$V(S_4 \geq S_1) = 0.028;\ V(S_4 \geq S_2) = 0.063;\ V(S_4 \geq S_3) = 0.679$

And,

$d'(A_1) = \min V(S_1 \geq S_k) = 1;\ d'(A_2) = \min V(S_2 \geq S_k) = 0.967$

$d'(A_3) = \min V(S_3 \geq S_k) = 0.359;\ d'(A_4) = \min V(S_4 \geq S_k) = 0.028$

Therefore the weight vector of main factors is:

$W' = [d'(A_1), d'(A_2), ..., d'(A_n)]^T$ = (1, 0.967, 0.359, 0.028)

After normalization, the normalized weight vector is:

$W =$ (0.4249, 0.4109, 0.1525, 0.0117)

Similarly, we can obtain the local weights and global weights of all sub-factors in Table 3 with the same approach. Based on the results in Table 3, the top five most critical factors for traffic volume of PPP transportation projects in Vietnam in descending order of importance are:

1) Level of project toll fee and the affordability of users
2) Benefits and safety for using facilities
3) Quality of project services and connecting networks
4) Advantage or disadvantage of the tollbooths
5) The designed traffic volume and development of connecting facilities

3.1. Level of project toll fee and the affordability of users

The results manifest that the most influential factor for traffic volume of PPP transportation projects in Vietnam is the level of project toll fee and the affordability of users. The issue of toll fee as vehicles passing the BOT project is always a prime concern of users, especially in developing countries like Vietnam. In fact, users have many options for making their itinerary trips. Thus, they will take into account of different toll rates of various alternative routes and their affordability. Uncertainty of user willingness to pay a fee in toll BOT projects, especially when tolls are higher than average, is one of the primary drivers for traffic demand risk [8].

Table 3: The Weights and Ranking of Main Factors and Sub-Factors

Code	Local weights	Global weights	Local rank	Global rank
F1		0.4249		
F11	0.3660	0.1555	1	1
F12	0.0695	0.0295	4	12
F13	0.2136	0.0908	3	4
F14	0.3509	0.1491	2	2
F2		0.4109		
F21	0.2772	0.1139	1	3
F22	0.1962	0.0806	3	6
F23	0.2192	0.0901	2	5
F24	0.1273	0.0523	5	8
F25	0.1363	0.0560	4	7
F26	0.0440	0.0181	6	14
F3	0.1525			
F31	0.2337	0.0356	3	11
F32	0.2820	0.0430	2	10
F33	0.3184	0.0486	1	9
F34	0.1423	0.0217	4	13
F35	0.0236	0.0036	5	17
F4		0.0116		
F41	0.603	0.0071	1	15
F42	0.338	0.0039	2	16
F43	0.059	0.0007	3	18

3.2. Benefits and safety for using facilities

Upon considering the toll fee to be paid, project users usually examine the advantages of using the service, especially time saving and fuel saving. For example, the tolls of the BOT Noi Bai - Lao Cai project are quite expensive. In fact, the tolls for 10- to 18-ton trucks with 20-ft containers are 760,000 VND per trip. However, this project is estimated to save 3 or 4 hours, as compared with those for the former route (i.e., National Highway 70). This BOT project also helps users to save fuel 20% to 30%, as compared with those of the former route. Specifically, it can save nearly 400,000 VND per trip for heavy trucks and approximately 700,000 VND a trip for buses.

3.3. Advantage or disadvantage of the tollbooths

Improper toll booth location and its management technology affect the capability to collect toll fee and project operation. For example, at the site of BOT National Highway 6 project, local people blocked the tollbooths to protest not only the overcharging of tolls, but also their locations in densely populated areas. Another example is Binh Trieu 1 Bridge in Hochiminh City. In 2013, this project faced with critical traffic congestion, especially during the peak hours. This is because it adopted a stopping tollbooth technology. To mitigate such traffic congestion, by the end of 2013 the toll collection management company of Binh Trieu Bridge 1 had to replace such technology with a new non-stop toll system [24].

Designed traffic volume and development of connecting facilities

The objectives of the connecting facilities are to collect and spread the traffic volume for the main facility. A total traffic volume through the associated facilities is equal to the traffic volume passing the main facility, so the traffic volume in the connecting facilities must meet the traffic demands. If the traffic volume in the connecting facilities is less than those of the actual traffic volume of the main facility, it will cause traffic congestion. Moreover, if the development of connecting facilities of a BOT project is expanded, it also expands the nearby residential areas nearby. This will subsequently increase traveling demand, resulting in increasing traffic volume.

4. Conclusion

PPP is considered a new form of infrastructure project investment in developing countries [25]. A risk factor that significantly affects the success of PPP transportation projects in Vietnam is traffic volume [26], [27]. Using fuzzy extended analytic method (FEAM), the relative importance of different factors influencing traffic volume in PPP transportation projects can be prioritized. The results show that the top five most critical factors for traffic volume of PPP transportation projects in Vietnam are (1) Level of project toll fee and the affordability of users, (2) Benefits and safety for using facilities, (3) Quality of project services and connecting networks, (4) Advantage or disadvantage of the tollbooths, and (5) designed traffic volume and development of connecting facilities.

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