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Quantitative Assessment of the Likelihood of Disputes in PPP Projects Using Fault Tree Analysis

Xiaoxiao Zheng [1,*], Yisheng Liu [1], Jun Jiang [2] and Nan Su [3]

[1] Department of Construction Management, Beijing Jiaotong University, Beijing 100044, China; yshliu1@bjtu.edu.cn
[2] Department of Construction Management, Beijing University of Civil Engineering and Architecture, Beijing 100044, China; jiangjun@bucea.edu.cn
[3] Department of Civil and Construction Engineering, National Yunlin University of Science and Technology, Yunlin 64002, Taiwan; sun@yuntech.edu.tw
* Correspondence: xxzhengbucea@163.com

Abstract: Disputes involved in public–private partnership (PPP) projects destroy the relationship between governments and private partners and generate huge losses. To multiply the chances of successfully preventing disputes, a holistic understanding of how a PPP dispute occurs is necessary. This paper contributes to the PPP dispute studies domain in (1) identifying various contributors that lead to the formation of PPP disputes at different levels, (2) proposing a fault tree (FT) framework of a PPP dispute, and (3) evaluating the likelihood of a PPP dispute and displaying the weakest part of a PPP project. First, three basic components that drive the development of PPP disputes are identified: project uncertainty, opportunistic behaviors, and contractual incompleteness. Second, scenario modeling of PPP disputes through fault tree analysis (FTA) depicts a more intelligible structure of PPP disputes. Furthermore, the fuzzy sets evaluation method was employed to compute the fuzzy occurrence likelihood of a PPP dispute. The results indicate that dispute is inevitable in PPP projects (with an occurrence likelihood of 0.9464). Additionally, opportunism is the dominant dispute inducer in PPPs. Our findings are expected to help PPP participants understand how various drivers contribute to the occurrence likelihood of PPP disputes where past data is inadequate. Then, more cost-efficient and appropriate preventive strategies can be developed based on the assessment to minimize the occurrence of PPP disputes.

Keywords: public–private partnership; disputes; fault tree analysis (FTA); fuzzy likelihood

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1. Introduction

The public–private partnership (PPP) model is becoming the preferred procurement option used in public infrastructure projects, because the involvement of private capital offers an opportunity to relieve government financial burdens and to improve the quality of service compared to the conventional procurement method [1,2]. Following the global financial crises of 2007–2008, the PPP financial strategy has become widely acknowledged by governments in both developed and developing countries [3].

Nevertheless, many PPP projects have failed because of the emergence of disputes between the public and private sectors. For instance, more than 1000 lawsuits in PPP projects occurred during the recent decade in China [4]. Unlike the conventional bid–build construction projects, PPP projects often involve multiple stakeholders, long-term arrangements, and high values [5–7]. There is a higher probability of dispute occurrence in PPPs than in traditional construction projects, because disputes may occur not only in the construction stage but also in the operation and transfer stages [8]. Although effective dispute resolutions are also essential for PPP projects [9–12], this paper serves as a warning of the possibilities of a dispute in PPP projects by evaluating the likelihood of disputes occurring.

While the disputes are undoubtably destructive to PPP projects, how the interactions of dispute contributors affect the likelihood of a PPP dispute remains a puzzle to be solved. Some recent research on PPP disputes has focused on specific causes at the same level, such as unreasonable risk allocation, public opposition, inaccurate demand forecast, unexpected tariff changes, etc. [13–16]. This study moves beyond the consideration of individual PPP dispute causes and constructs a framework to illustrate how various drivers at different levels contribute to the likelihood of PPP disputes occurring.

The assessment of the likelihood of a complex PPP dispute occurring is often difficult when past data are inadequate. A fault tree analysis (FTA) provides a framework for qualitative or quantitative analysis of a system's defects and weaknesses [17]. Therefore, this study introduces the FTA approach as an effective tool used to quantify the possibility of an occurrence. The fault tree (FT) framework includes scenario modeling of PPP disputes whereby the various components are combined through logic gates and systematic processing of expert assessments. In this format, the development of PPP disputes can be depicted more intelligibly. The description of PPP disputes by proposing an FT approach will hopefully guide stakeholders in the successful implementation of PPPs by providing guidance to both government and private partners about the weakest part of a PPP project. Given the significant losses caused by disputes, an understanding and the quantitative assessment of the development of PPP disputes provided by this study offer a roadmap to investors and public authorities for generating the most suitable dispute prevention strategies. Furthermore, the results of this study provide a solid theoretical foundation for empirically investigating PPP disputes within the existing international PPP literature and contribute significantly to the body of knowledge on PPP.

In the following sections, first, various contributors to PPP disputes at different levels are identified. Next, they are arranged under an FT framework to illustrate the formation of PPP disputes. Then, a workshop was conducted to validate this framework. Furthermore, based on possibility theory, experts' assessments with fuzzy sets are introduced to estimate the likelihood of PPP disputes occurring. Finally, the discussions and conclusions are presented.

2. Literature Review

2.1. Application of PPPs

The PPP procurement method has been widely used in the construction industry to serve the high demand for infrastructure development [18]. A growing body of evidence suggests that PPP can be efficiently used on different types of large-scale projects of public importance, such as the transportation infrastructure of toll roads, bridges, or tunnels [19] and the municipal infrastructure, as well as buildings and facilities intended for public housing and care and hospitals [15].

A significant amount of studies have made great efforts in the application of PPPs in traditional infrastructures. Considering the existing transportation infrastructure is aging and the shortage of funds in the United States, Papajohn et al. [20] demonstrated that the PPP financing method is a potential mechanism to help meet this looming need. In order to ensure tariff discipline and improve efficiency and governance in public water utilities, Ameyaw et al. [21] investigated the critical factors for attracting private capital participation in public water utilities in developing countries. For relieving the government's budgetary burden, European governments are increasingly cooperating with private sectors to construct and operate public hospitals and other healthcare facilities [22]. In recent decades, the PPP approach has also been proven to be an effective financing tool to solve the problem of insufficient sewage treatment facilities and improve the efficiency of sewage treatment [23].

There are also several important attempts to explore the application of PPPs in other sectors. Liu and Wilkinson [24] evaluated PPP experiences in the prison sector and recommended strategies and measures for the development of PPPs for the prison. Yuan et al. [25] indicated that the introduction of private capital into the development of public housing was promoted by the Chinese governments to improve the quality of public

housing. Kirikkaleli and Adebayo [26] recommended that private investment should be enhanced in renewable energy to achieve cleaner production processes. Under the need for sustainable urban development, Jayasena et al. [27] conducted a holistic literature review to provide a basis for the introduction of the PPP method in the construction of smart infrastructure.

In conclusion, global support for different types of PPP projects has seemed stronger than ever before over the last two decades. However, disputes remain the biggest obstacle to the successful implementation of PPPs. Against this backdrop, this study aims to find a warning before PPP project initiation by exploring the occurrence of PPP disputes.

2.2. Occurrence of Disputes in PPPs

The characteristics of PPP projects make them prone to disputes. Resolving disputes is time-consuming and costly, and the damages caused by disputes are often destructive to PPP projects [28]. Therefore, studies of PPP disputes are garnering more and more attention from researchers. Besides the identification of various causes of disputes, a holistic understanding of the formation of a dispute is also essential for preventing and resolving disputes. Thus, we need to understand the literature surrounding disputes.

2.2.1. Potential Dispute Causes

First, some studies in the literature have explored the causes of disputes in PPP projects. The literature review was conducted comprehensively to cover different types of countries. The potential dispute causes of PPP projects are summarized in Table 1.

Table 1. Summary of potential dispute causes.

No.	Potential Dispute Causes	Country/Continent	References
1	Site availability, unstable government, force majeure, legislation change, change in tax regulation, poor public decision-making process, public opposition, level of demand for project, etc.	The U.K.	[29]
2	Land acquisition, unstable government, force majeure, expropriation or nationalization, poor public decision-making process, public opposition, change in tax regulation, etc.	China, the U.K., and Greece	[30]
3	Delays in expropriation, political stability, force majeure, competition issues, etc.	Portugal	[31,32]
4	Unexpected tariff changes, political interference, unfair risk allocation, delay in decision makings, etc.	Ghana and China	[14]
5	Delays in expropriation, changes in regulations, unreasonable risk allocation, the emergence of competitive projects, unqualified public service, default of payment, repudiation of contracts, public opposition, etc.	China	[15,16]
6	Delay in expropriation, force majeure, specific legal changes, administrative delays, etc.	Latin American	[33]
7	Unstable political system, inequitable risk allocation, unstable economic system, inefficient legal framework, etc.	Malaysia and Nigeria	[34]
8	Site accessibility, strong political interference, quality of service, market competition, demand risk, payment delay, force majeure, changes in legislations and/or regulations, political/public opposition, etc.	Egypt	[35]
9	Unstable political and social environment, unstable macroeconomic environment, unfavorable legal frameworks, poor governance, etc.	Ethiopia	[36]

The literature summarized in Table 1 shows that both developing and developed countries have similar potential causes of PPP disputes (i.e., delays in expropriation, unstable government, public opposition, etc.). What differs is the significance or probability of the causes within different territorial contexts. For instance, Debela [36] compared the

differences of the top five critical success factors (CSFs) of PPPs between Ethiopia and other developing countries (Uganda, Nigeria, Indonesia, Ghana, and China) based on the same list of CSFs. Ke et al. [30] analyzed the risk allocation preferences in PPP projects of mainland China and the Hong Kong Special Administrative Region and then compared these preferences to those in the U.K. and Greece based on the same risk register.

2.2.2. The Development of Disputes

Other studies have attempted to explore the developmental process of disputes. Using the structural equation model (SEM), Molenaar et al. [37] proved that project complexity and unfair risk sharing are two main contributors in the occurrence of disputes. Likewise, to explain the formation of a dispute, Mitropoulos and Howell [38] applied a process model to present the combined effect of project uncertainty, contract problems, working relations, and problem-solving effectiveness. Cheung and Yiu [39] proposed that disputes are the intersection of three basic artifacts: contract stipulations, dispute triggering events, and conflict. Sinha and Jha [40] put forward successive stages to illustrate the development of PPP disputes: from unfair risks to conflicts and from unsolved conflicts to disputes. Furthermore, Tanriverdi et al. [41] used the causal mapping approach to present the emergence of construction disputes and highlighted the impact of preconstruction studies, people factors, and contract terms.

2.3. Fault Tree Analysis

The FTA approach was first developed in the early 1960s to estimate the safety and reliability of the system [42]. An FT framework is a logic diagram that describes the logical relationships between the top event in the system and the ingredients that make up this event [43]. The basic structure of an FT is shown in Figure 1. The top event (TE), such as a loss, a failure, an accident, a dispute, or an undesirable event, is first arranged; then, the subevents/contributors that lead to this event are identified [44]. The top or head event is further decomposed into subevents, until the basic events (BEs) are reached. The combination events (CE) are used to connect the BEs and the TE. Basic events are events that cannot be further decomposed.

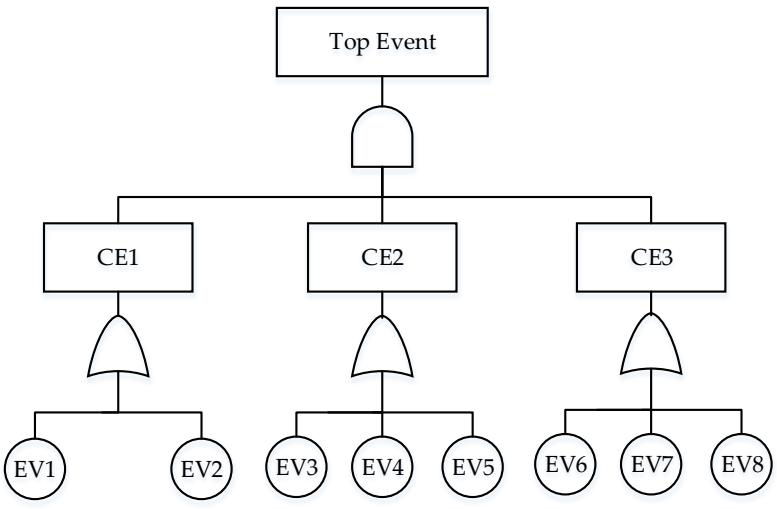

Figure 1. Example of a fault tree structure.

The logic gates—AND (∩) and OR (∪)—are commonly used to represent the relationships among different levels of events. In FTA, if the probability of lower-level events occurring is given, a deterministic assessment of the likelihood of the top or higher-level event occurring can become available using algebraic operations.

The symbols in Figure 1, as interpreted by Cheung [45], the circle means that a basic event cannot be further decomposed; the rectangle describes an output event for basic

events combined through logic gates. The AND gate (⌓) depicts a situation in which only the simultaneous existence of all input events can produce the output event; the OR gate (⌔) defines the logical operation in which the output event will occur if one or more of the input events occur.

FTA is a method that serves to identify and analyze the weakest part or the failure scenarios of a system. Considering that the relationships among various components of the top event can be clearly shown in an FTA, several studies and efforts have been conducted based on quantitative assessments using the FTA technique. For example, Thomas et al. [46] put forward the risk occurrence assessment framework of BOT road projects based on the FTA approach when past data were not available. Based on the possibility theory, Pan [47] assessed the building performance by combining fuzzy sets and FTA. In order to explore the different contributors to construction risk and to develop cost-efficient strategies, Abdelgawad and Fayek [48] applied FTA to assess the risk in construction projects. Cheung and Pang [49] proposed a framework of traditional bid–build project disputes using the FTA approach. Then, an example was used to evaluate the likelihood of a dispute occurring.

In practice, a dispute in the life cycle of PPP projects can be seen as a failure in a complex system. Thus, FTA is suitable for evaluating the probability of PPP disputes and for identifying the most significant drivers in the development of disputes. Then, more cost-efficient strategies can be developed based on the assessment to minimize the likelihood of a dispute occurring.

2.4. Knowledge Gap

Previous research on PPP disputes mostly focused on listing the potential causes of PPP disputes, which can hardly be used by public and private sectors to understand the logical relationships among these causes and how these causes intersect together to contribute to the formation of PPP disputes. In addition, the existing literature does not allow for a quantitative assessment of the likelihood of various factors contributing to a PPP dispute. Therefore, PPP disputes need to be regarded as a failure system to identify the weakest part of a PPP project.

To address these knowledge gaps, this study offers an alternative approach to understanding the development of PPP disputes and using FTA to evaluate the likelihood of PPP disputes occurring. Essentially, the FT framework of PPP disputes proposed provides important information to support decisions for decision-makers to assess the probability of a dispute in advance. Furthermore, the FT framework and evaluative tool used to assess PPP disputes in this study are generic. Therefore, they can be consulted or applied to suit different PPP projects in different territorial contexts with appropriate modifications.

3. Research Methodology

The aim of this paper is to estimate the likelihood of a dispute occurring in PPPs. First, the various contributors to PPP disputes at different levels are identified; then, they are arranged under an FT framework. This arrangement shows the logical relationships among various contributors and allows for a quantitative assessment of dispute events. Finally, the weakest part of the PPP project can be identified, which will help both public and private sectors understand and manage PPP disputes. The methodology is shown in Figure 2.

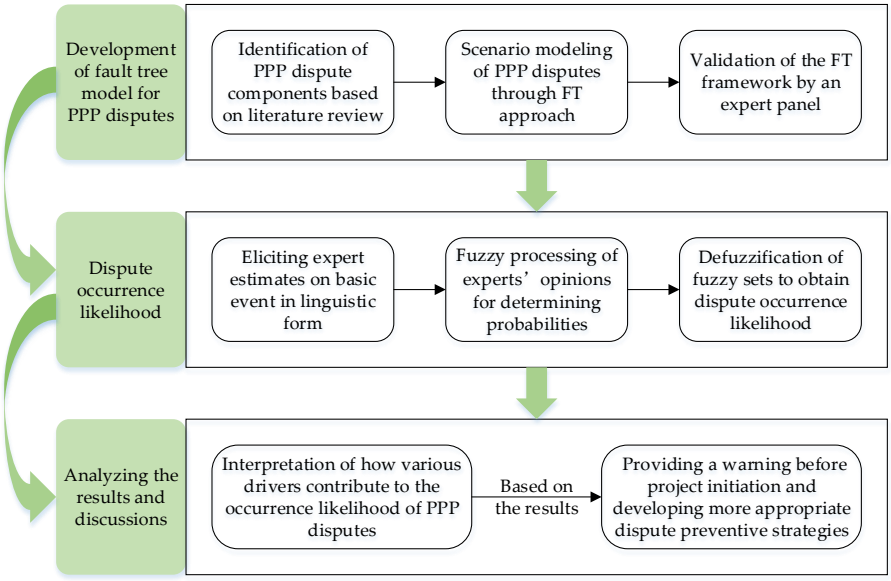

Figure 2. Research methodology.

3.1. Development of Fault Tree Model of PPP Disputes

Three steps are involved in the development of an FT model for PPP disputes:

1. Identifying the components of a PPP dispute,
2. Scenario modeling of PPP disputes using an FT approach, and
3. Validating the FT framework.

Identifying the components of a PPP dispute constitutes the first step towards framing an FT model. To ensure that all possible components are covered, a thorough literature review on the development of PPP disputes was conducted. The basic components based on Mitropoulos and Howell's [38] opinion were identified, and the three basic ingredients of dispute development are project uncertainty, opportunistic behaviors, and contractual incompleteness. Uncertainty often results in an unexpected situation, which is defined as a problem [38]. The emergence of problems directly affects the behaviors of the public and private sectors. In PPP projects, contract parties may behave opportunistically to serve their self-interests [50]. For example, the public sector may reject offering subsidies or adjusting the contract price/period for a revenue shortage caused by demand changes. Once opportunism appears, problems can easily escalate into conflicts. An incomplete contract may be unable to deal with conflicts [51]. Thus, an unresolved conflict would stimulate disputes. The conceptual model of PPP dispute development is illustrated in Figure 3.

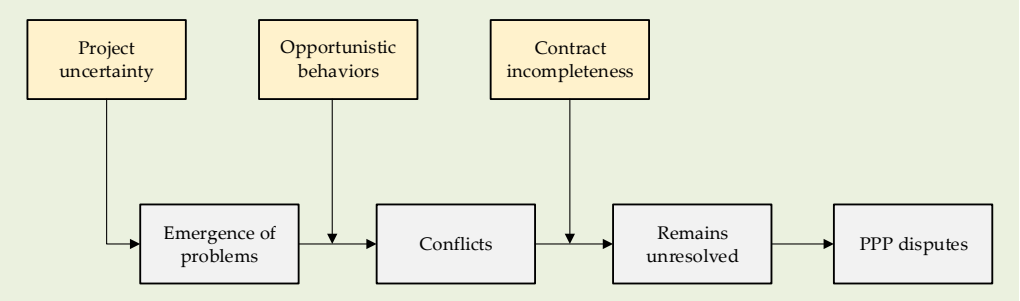

Figure 3. Conceptual model of a PPP dispute.

Furthermore, project uncertainty falls into two subcategories: external and internal; opportunistic behaviors as the violation of commitment and evasion and refusal to adapt change [52]; and contract incompleteness as ambiguity, deficiency, and inconsistency [49].

The components of a PPP dispute and the references from which they were obtained are listed in Tables 2–4.

Table 2. Components of PPP disputes (project uncertainty).

Symbol	Description	References
Uncertain external environment		
PU1	Change in regulations	[13,15,16,53,54]
PU2	Public/political opposition	[15,16,54]
PU3	Nationalization	[13,54]
PU4	Unexcepted tariff changes	[14,54,55]
PU5	Economic downturns or upturns (impact demand and costs)	[31,53]
PU6	Political instability/Unstable government	[3,31]
PU7	Force majeure	[14,30,32,56]
Internal characteristics of project		
PI1	Design, construction, and operation complexity	[37,41]
PI2	Investment/duration (size/scale of the project)	[31,37]
PI3	Nonexistence of previous similar projects (Pioneer project)	[37]

Table 3. Components of PPP disputes (opportunistic behaviors).

Symbol	Description	References
Violation of commitment		
OV1	The public sector does not complete the land acquisition within the stipulated time	[15,16,32]
OV2	The public sector does not honor its commitment to exclusive guarantee and builds other competitive projects	[13,15]
OV3	In government pay/viability gap funding models, the public sector does not pay fees/feasibility gap subsidies in full and on time	[13,15,16,54]
OV4	The private sector spends a longer construction time than committed	[15,54]
OV5	The private sector does not have sufficient capital to construct, operate, and maintain the PPP project	[13,15]
OV6	The private sector provides poor service/product quality to the public	[15]
Evasion and refusal to adapt change		
OE1	The public sector rejects offering subsidies or adjusting the contract price/period for the revenue shortage caused by unexpected changes	[13]
OE2	The contracting parties reject communicating with each other	[16]

Table 4. Components of PPP disputes (Contract incompleteness) [15].

Symbol	Description
Ambiguity	
CA1	The specific conditions and procedures of termination of the PPP contract are unclear.
CA2	When the PPP contract is terminated due to force majeure or law changes (unexpected changes), the specific calculation of reasonable investment rewards is unclear.
CA3	The specific deadline for expropriation and the penalty for expropriation delays is unclear.
CA4	The issues in the governments repurchasing, such as the repurchase price, payment method, and repurchase procedure, are unclear.
CA5	The obligations and responsibilities for termination of the contract due to public opposition are unclear.
CA6	In government pay/viability gap funding models, the compositions of payment, payment calculation formula, payment source, payment process, payment time, etc. are unclear.

Table 4. *Cont.*

Symbol	Description
Deficiency	
CD1	The clauses about the compensation of expected revenues (benefits due to continued performance of the contract) if the PPP contract is terminated prematurely are not stipulated
CD2	In projects where raw materials are not available from the open market and can only be supplied by the government (such as sewage), the minimum revenue guarantee (MRG) or minimum demand guarantee (MDG) are not provided
CD3	No statement was made in the contract on exclusive guarantees
CD4	No explicit stipulations were made in the contract about the obligations and responsibilities for failure to obtain project approval and permits
Inconsistency	
CI1	The specified standards of the quality of public products or services are inconsistent with the statutory requirement
CI2	The charging standard in the PPP agreement is different from the standard agreed upon in the project implementation plan

Scenario modeling of PPP disputes using the FT approach depicts a clear structure of PPP disputes. The PPP dispute analysis, in general, deals with complex and uncertain systems. In this regard, probabilistic modeling is more effective and reasonable than the direct evaluation of dispute events. If a model that interconnects the top event with underlying factors is framed, the occurrence likelihood assessment of the top event can be more easily with greater confidence [43]. Based on the literature findings, an initial FT framework was built to collect an expert panel's comments.

A workshop with the participation of an expert panel (14 experts) was designed to validate the FT framework. The experts' backgrounds are summarized in Table 5. All panel members are experienced in PPP projects and dispute resolution. The first session of the workshop focused on the introduction of the research aim, methodology, and FT approach. A semi-structured discussion was designed to help experts to discuss and express their views on the occurrence of PPP disputes more clearly. Questions such as "In your experience, what's the major role in triggering PPP disputes" and "What were the causes of the dispute you encountered in PPP projects?" were directed at the experts. Meanwhile, the laddering method [57] was introduced to investigate the underlying causes, outcomes, and their relations. Hence, the question "In your opinion, how do you relate the underlying issues together to form a PPP dispute?" was presented to the experts. In the next session, an initial FT framework of PPP disputes was shown on a projection screen. Visual images provided a better approach for experts to express insightful opinions based on their previous experience. These experts offered an overall view on the correcting links between factors, eliminating reduplicative statements and irrelevant factors or events, as well as adding omissive concepts. The final FT framework of PPP disputes endorsed by the expert panel is exhibited in Figure 4.

Table 5. Profiles of the expert panel.

No.	Roles in PPP Projects	Number of Experts	Experience (Years)		
			<10	10–15	>15
1	Central government	1		1	
2	Local government	2	1	1	
3	Private sectors	4	1	2	1
4	Consultant	2		1	1
5	Lawyer	4	1	2	1
6	Contractor	1	1		

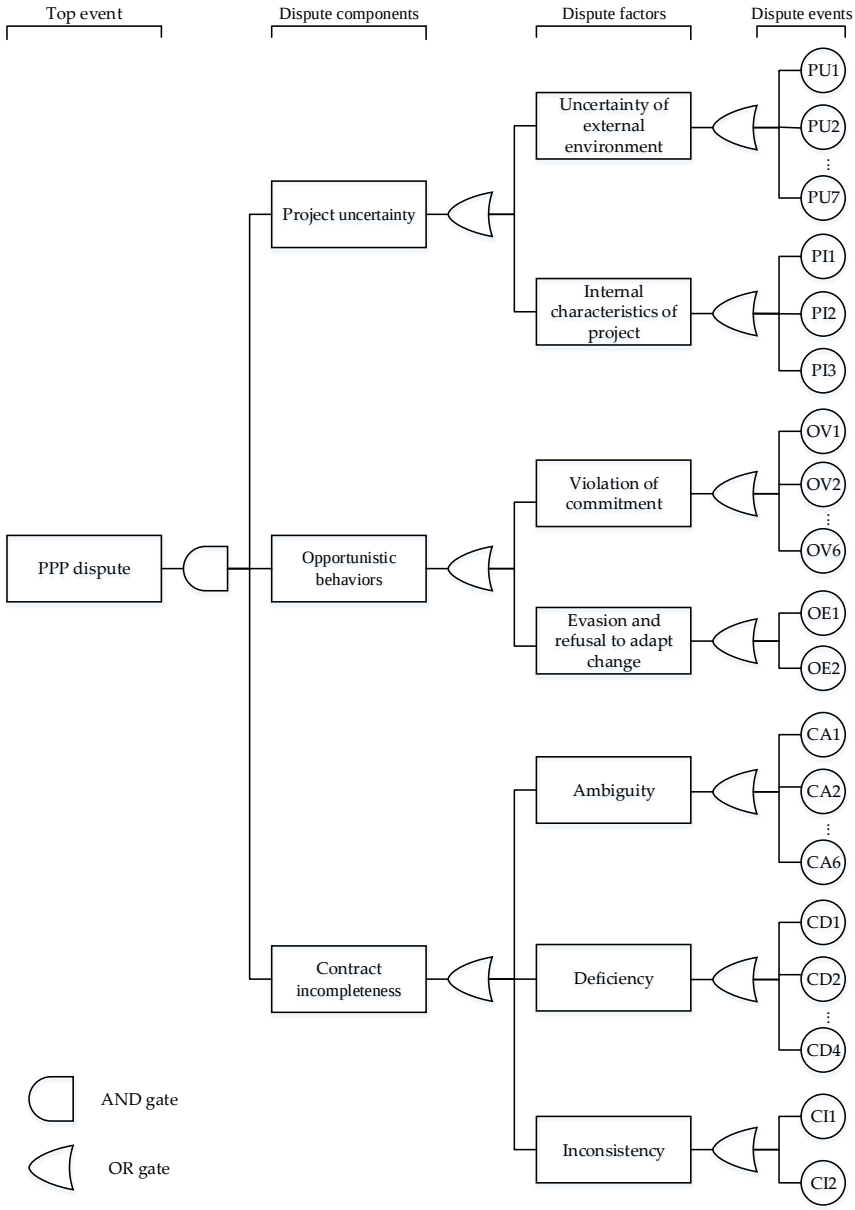

Figure 4. The fault tree framework of PPP disputes.

3.2. Fuzzy Occurrence Probability

3.2.1. Fuzzy Sets and Membership Function

(1) Fuzzy sets

The proposed FT model of PPP disputes provides an opportunity to quantify the likelihood of PPP disputes. Once the probabilities of the terminal event in the FT are available, the likelihood of the top event can be evaluated. In the proposed PPP dispute FT framework (Figure 4), where the exact likelihood of the terminal dispute events occurring is not available, using classical probability to estimate the probability of a PPP dispute (top event) occurring is difficult. However, in general, the probability of an occurrence can be assessed by PPP experts with rich experiences and can be expressed in imprecise linguistic terms. Thus, a fuzzy set evaluation is more appropriate for modeling linguistic variables than discrete probabilities in this study.

Fuzzy sets can be a powerful tool used to quantify human judgmental variables. Zhao and Bose [58] conducted a comparison of the performance of symmetrical membership functions with different variables and demonstrated that seven fuzzy sets represent the

optimal case for a symmetrical triangular membership function. Seven linguistic variables—namely, extremely low, very low, low, medium, high, very high, and extremely high—were used to estimate the likelihood of terminal dispute events occurring in the proposed FT. The fuzzy restrictions and membership functions assumed are given in Table 6.

Table 6. Linguistic variables in the triangular membership functions.

Symbol	Linguistic Score	Fuzzy Parameters (a, b, c)
EL	Extremely low	(0.00, 0.125, 0.25)
VL	Very low	(0.125, 0.25, 0.375)
L	Low	(0.25, 0.375, 0.50)
M	Medium	(0.375, 0.50, 0.625)
H	High	(0.50, 0.625, 0.75)
VH	Very high	(0.625, 0.75, 0.875)
EH	Extremely high	(0.75, 0.875, 1.00)

(2) Membership function

In fuzzy sets, the degree of belief from the "belong to set" to the "not belong to set" of each fuzzy subset is gradual, and the transition is represented by membership function (MF). An MF with values in the interval [0, 1] is used to measure the degree of belief of every fuzzy subset. The triangular membership function (TMF) of the seven fuzzy subsets is presented in Figure 5. The x-axis shows the probability, and the y-axis represents the membership functions.

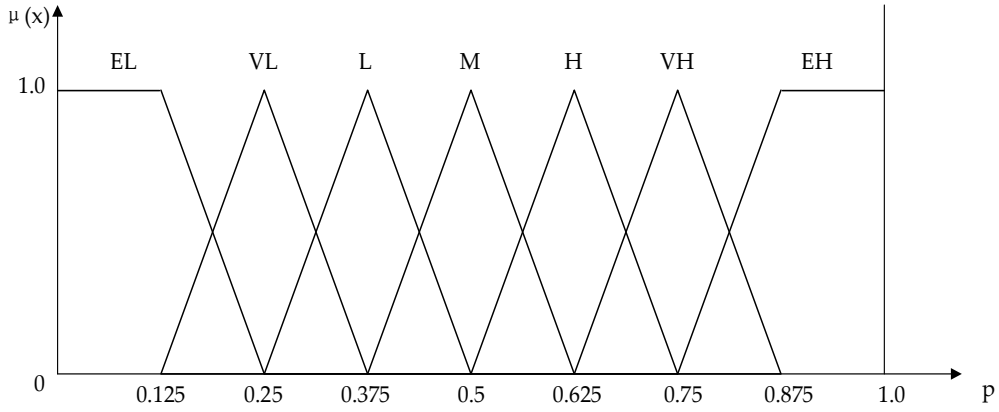

Figure 5. Fuzzy probability–representation of the triangular membership functions.

3.2.2. Operations on Fuzzy Sets

Let $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ be two positive triangular fuzzy numbers. According to Kaufmann and Gupta [59], the operations $[+, -, \times, \div]$ are expressed as Equations (1)−(4):

$$A_1 \oplus A_2 = (a_1, b_1, c_1) \oplus (a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (1)$$

$$A_1 \ominus A_2 = (a_1, b_1, c_1) \ominus (a_2, b_2, c_2) = (a_1 - c_2, b_1 - b_2, c_1 - a_2) \quad (2)$$

$$A_1 \otimes A_2 = (a_1, b_1, c_1) \otimes (a_2, b_2, c_2) = (a_1 \otimes a_2, b_1 \otimes b_2, c_1 \otimes c_2) \quad (3)$$

$$A_1 \odot A_2 = (a_1, b_1, c_1) \odot (a_2, b_2, c_2) = (a_1 / c_2, b_1 / b_2, c_1 / a_2) \quad (4)$$

where $\oplus$, $\ominus$, $\otimes$, and $\odot$ represent the fuzzy operations addition, subtraction, multiplication, and division, respectively.

3.2.3. Aggregation and Defuzzification of Fuzzy Sets

(1) Aggregation

Aggregation means the integration of different membership functions [47]. The experts' fuzzy possibility scores indicate their opinions on the possibility that an event may occur. After collecting the experts' fuzzy possibility scores, the respondents' opinions need to be integrated into one [60]. The most common method of aggregation is the fuzzy mean. The aggregated value is calculated through Equations (5)−(7):

$$A_i = \left(\frac{1}{n}\right) \otimes (a_1 \oplus a_2 \oplus \cdots \oplus a_n)\ i = 1,\ 2,\ \cdots, n \tag{5}$$

where a is the first fuzzy parameter of linguistic variables in triangular membership functions, and n is the total number of experts/respondents:

$$B_i = \left(\frac{1}{n}\right) \otimes (b_1 \oplus b_2 \oplus \cdots \oplus b_n)\ i = 1,\ 2,\ \cdots, n \tag{6}$$

where b is the second fuzzy parameter:

$$C_i = \left(\frac{1}{n}\right) \otimes (c_1 \oplus c_2 \oplus \cdots \oplus c_n)\ i = 1,\ 2,\ \cdots, n \tag{7}$$

where c is the third fuzzy parameter.

(2) Defuzzification

The fuzzy set has to be represented by a nonfuzzy or crisp value to adequately illustrate the degree of impact of the aggregated fuzzy number, which means defuzzification [61]. By defuzzifying the fuzzy possibility of the top event, the occurrence likelihood of a PPP dispute in the FT model can be assessed. Shaheen et al. [62] demonstrated that the defuzzified possibility score (DFS) equals the expected value of a triangular probability distribution, which is given by Equation (8):

$$DFS = (A_i + B_i + C_i)/3 \tag{8}$$

where A_i, B_i, and C_i are the aggregated fuzzy parameters in the fuzzy set.

3.2.4. Evaluation of Likelihood of a Dispute in Fault Tree

Once the experts' fuzzy possibility scores of the basic events become available, the probability of the top event (a PPP dispute) and the intermediate events (i.e., dispute factors) occurring can be assessed based on fuzzy set operations and the logical operators (AND and OR gates) in the FT. For a higher-level event E_n that has an output from the AND gate with basic events $E_1, E_2, \ldots, E_m$ as the inputs, the probability of a fuzzy occurrence of event E_n can be expressed as Equation (9):

$$\widetilde{P_{E_n}} = \widetilde{P_{E_1}} \otimes \widetilde{P_{E_2}} \otimes, \ldots\ldots, \otimes \widetilde{P_{E_m}} \tag{9}$$

Analogously, the probability of a fuzzy occurrence with an OR gate is determined using Equation (10):

$$\widetilde{P_{E_n}} = 1 - \left(1 - \widetilde{P_{E_n}}\right) \otimes \left(1 - \widetilde{P_{E_2}}\right) \otimes, \ldots\ldots, \otimes \left(1 - \widetilde{P_{E_m}}\right) \tag{10}$$

where $\widetilde{P}$ is the triangular fuzzy probability.

4. Fuzzy Likelihood of PPP Dispute Occurring

4.1. Data Source

The data used to evaluate the likelihood of the 30 basic dispute events listed in Tables 2–4 were collected from questionnaires. First, the FT framework of a PPP dispute was introduced to respondents. Then, the fuzzy linguistic rating scales presented in Table 6

were used for respondents to assign the fuzzy occurrence likelihood. Notably, the results of the assessment mostly depend on the experts, so the respondents' hands-on experiences with PPPs are essential to ensuring the quality of the judgment. Furthermore, a total of 110 questionnaires from China were received from (1) a panel from officials of central and local governments, (2) companies with PPP investment experience, (3) law firms, (4) consulting firms, and (5) construction companies. The sample size is close to that of Cheung and Yiu [39]. Among these experts, 60% have more than 10 years of PPP experience. Figure 6 lists the respondents' roles.

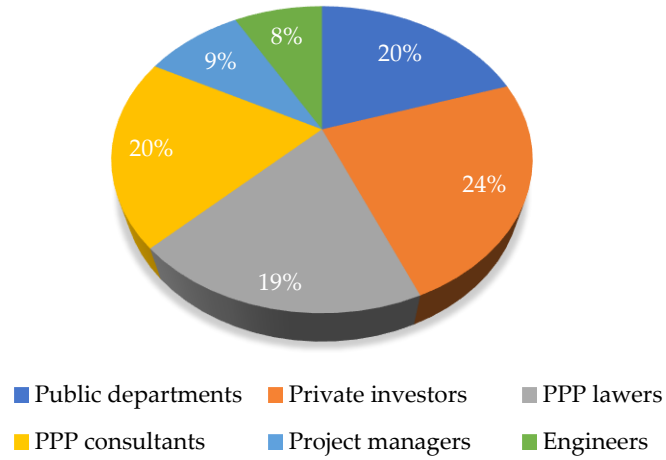

Figure 6. Respondents' roles in PPP projects.

The main data collection instruments in this study were face-to-face interviews and email. The interview method has been employed extensively in construction management studies to solicit participants' comments on the topic, as it allows a deep interpretation of the subject matter [63,64]. Nevertheless, because it is difficult to collect all data through interviews, email is another efficient instrument to collect questionnaires in the construction industry [65]. Questionnaires can be distributed via emails to respondents who are interested in the topic but are not available for an interview.

In this study, nearly 30 respondents were interviewed via face-to-face meetings. Before they assigned fuzzy scores of these 30 basic dispute events, a semi-structured questionnaire was adopted to solicit qualitative data for follow-up discussions. The key interview questions include:

- Different types of disputes encountered in project development and the main reasons given to induce these disputes,
- Assessment of the probabilities of these underlying reasons, and
- Strategies or mechanisms proposed to avoid or mitigate the occurrence likelihood of disputes in PPP projects.

The other questionnaires were distributed via email. Finally, all the questionnaire data were summarized through Microsoft Excel for the result calculations.

4.2. Results

Following the aforementioned steps for assessing the probability of fuzzy occurrence indicated in Equations (5)–(8), we list the aggregation of 110 expert linguistic scores (fuzzy parameters) and the defuzzified occurrence values of the PPP dispute components in Tables 7–9.

Table 7. Occurrence likelihood of project uncertainty.

	Dispute Components	Aggregated Fuzzy Parameters	Defuzzified Value
	Project uncertainty	(0.9295, 0.9884, 0.9987)	0.9722
	Uncertain external environment	(0.8082, 0.9438, 0.9875)	0.9132
PU1	Change in regulations	(0.39, 0.51, 0.64)	0.5114 *
PU2	Public/political opposition	(0.17, 0.30, 0.52)	0.2955
PU3	Nationalization	(0.20, 0.33, 0.45)	0.3295
PU4	Unexcepted tariff changes	(0.15, 0.27, 0.40)	0.2727
PU5	Economic downturns or upturns (impact demand and costs)	(0.38, 0.50, 0.63)	0.5000 *
PU6	Political instability/Unstable government	(0.07, 0.19, 0.32)	0.1932
PU7	Force majeure	(0.05, 0.17, 0.30)	0.1705
	Internal characteristics of project	(0.6323, 0.7939, 0.8996)	0.7753
PI1	Design, construction, and operation complexity	(0.32, 0.44, 0.57)	0.4431
PI2	Investment/duration (size/scale of the project)	(0.34, 0.47, 0.59)	0.4659
PI3	Nonexistence of previous similar projects (Pioneer project)	(0.18, 0.31, 0.43)	0.3068

* Defuzzified values above 0.5.

Table 8. Occurrence likelihood of opportunistic behaviors.

	Dispute Components	Aggregated Fuzzy Parameters	Defuzzified Value
	Opportunistic behaviors	(0.9690, 0.9946, 0.9994)	0.9876
	Violation of commitment	(0.9231, 0.9789, 0.9960)	0.9660
OV1	The public sector does not complete the land acquisition within the stipulated time	(0.22, 0.34, 0.47)	0.3409
OV2	The public sector does not honor its commitment to exclusive guarantee and builds other competitive projects	(0.40, 0.52, 0.65)	0.5227 *
OV3	In government-pay/viability gap funding models, the public sector does not pay fees/feasibility gap subsidies in full and on time	(0.42, 0.55, 0.67)	0.5455 *
OV4	The private sector spends longer construction time than committed	(0.30, 0.42, 0.55)	0.4205
OV5	The private sector does not have sufficient capital to construct, operate, and maintain the PPP project	(0.44, 0.57, 0.69)	0.5682 *
OV6	The private sector provides poor service/product quality to the public	(0.28, 0.41, 0.53)	0.4091
	Evasion and refusal to adapt change	(0.5961, 0.7424, 0.8574)	0.7320
OE1	The public sector rejects offering subsidies or adjusting the contract price/period for the revenue shortage caused by unexpected changes.	(0.48, 0.60, 0.73)	0.6023 *
OE2	The contracting parties reject communicating with each other	(0.23, 0.35, 0.48)	0.3523

* Defuzzified values above 0.5.

Table 9. Occurrence likelihood of contract incompleteness.

	Dispute Components	Aggregated Fuzzy Parameters	Defuzzified Value
	Contract incompleteness	(0.9583, 0.9953, 0.9997)	0.9844
	Ambiguity	(0.8767, 0.9630, 0.9920)	0.9439
CA1	The specific conditions and procedures of termination of the PPP contract are unclear	(0.45, 0.58, 0.70)	0.5795 *

Table 9. *Cont.*

	Dispute Components	Aggregated Fuzzy Parameters	Defuzzified Value
CA2	When the PPP contract is terminated due to force majeure or law changes (unexpected changes), the specific calculation of reasonable investment rewards is unclear	(0.26, 0.39, 0.51)	0.3864
CA3	The specific deadline for expropriation and the penalty for expropriation delays is unclear	(0.06, 0.18, 0.31)	0.1818
CA4	The issues in the governments repurchasing, such as the repurchase price, payment method, and repurchase procedure, are unclear.	(0.43, 0.56, 0.68)	0.5568 *
CA5	The obligations and responsibilities for termination of the contract due to public opposition are unclear	(0.10, 0.23, 0.35)	0.2273
CA6	In government pay/viability gap funding models, the composition of payment, payment calculation formula, payment source, payment process, payment time, etc. are unclear	(0.36, 0.49, 0.61)	0.4886
	Deficiency	(0.5528, 0.7705, 0.8972)	0.7402
CD1	The clauses about compensation of expected revenues (benefits due to continued performance of the contract) if the PPP contract is terminated prematurely are not stipulated	(0.27, 0.40, 0.52)	0.3977
CD2	In projects where raw materials are not available from the open market and can only be supplied by the government (such as sewage), the minimum revenue guarantee (MRG) or minimum demand guarantee (MDG) are not provided	(0.11, 0.24, 0.36)	0.2386
CD3	No statement was made in the contract on exclusive guarantees	(0.23, 0.35, 0.48)	0.3523
CD4	No explicit stipulations were made in the contract about the obligations and responsibilities for failure to obtain project approval and permits	(0.10, 0.23, 0.35)	0.2273
	Inconsistency	(0.2443, 0.4460, 0.6165)	0.4356
CI1	The specified standards of the quality of public products or services are inconsistent with the statutory requirement	(0.13, 0.25, 0.38)	0.2500
CI2	The charging standard in the PPP agreement is different from the standard agreed upon in the project implementation plan	0.14, 0.26, 0.39	0.2614

* Defuzzified values above 0.5.

4.2.1. Fuzzy Probability of Project Uncertainty

The fuzzy probabilities for each PPP dispute component in Tables 7–9 are used to calculate the likelihood of PPP dispute factors and dispute components (Figure 4) using Equations (1)–(4), (9) and (10). The operation process is expressed as follows:

$$\begin{aligned}
&\widetilde{P_{\text{Uncertain external environment}}} = 1 - \left(1 - \widetilde{P_{PU1}}\right) \otimes \left(1 - \widetilde{P_{PU2}}\right) \otimes, \ldots\ldots, \otimes \left(1 - \widetilde{P_{PU7}}\right) \\
&= 1 - [1 - (0.39, 0.51, 0.64)] \otimes [1 - (0.17, 0.30, 0.52)] \otimes \ \ldots\ldots, [1 - (0.05, 0.17, 0.30)] \\
&= 1 - ((0.36, 0.49, 0.61)) \otimes (0.48, 0.7, 0.83) \otimes \ldots\ldots, \otimes (0.70, 0.83, 0.92) \\
&= 1 - (0.0125, 0.0562, 0.1918) = ((0.8082, 0.9438, 0.9875))
\end{aligned}$$

i.e., defuzzified value = (0.8082 + 0.9438 + 0.9875)/3 = 0.9132.

$$\begin{aligned}
&\widetilde{P_{\text{Internal characteristics of project}}} = 1 - \left(1 - \widetilde{P_{PI1}}\right) \otimes \left(1 - \widetilde{P_{PI2}}\right) \otimes \left(1 - \widetilde{P_{PI3}}\right) \\
&= 1 - [1 - (0.32, 0.44, 0.57)] \otimes [1 - (0.34, 0.47, 0.59)] \otimes [1 - (0.18, 0.31, 0.43)] \\
&= 1 - (0.43, 0.56, 0.68) \otimes (0.41, 0.53, 0.66) \otimes (0.57, 0.69, 0.82) \\
&= 1 - (0.1004, 0.2061, 0.3677) = (0.6323, 0.7939, 0.8996)
\end{aligned}$$

i.e., defuzzified value = (0.6323 + 0.7939 + 0.8996)/3 = 0.7753.

In Figure 4, either an uncertain external environment or the internal characteristics of the project would result in project uncertainty. Therefore, the fuzzy probability of project uncertainty is expressed as the project uncertainty = uncertain external environment ∪ internal characteristics of a project:

$$\begin{aligned}&\widetilde{P_{\text{Project uncertainty}}}\\&= 1-\left(1-\widetilde{P_{\text{Uncertain external environment}}}\right)\otimes\left(1-\widetilde{P_{\text{Internal characteristics of project}}}\right)\\&= 1-[1-(0.8082,0.9438,0.9875)]\otimes[1-(0.6323,0.7939,0.8996)]\\&= 1-(0.125,0.0562,0.1918)\otimes(0.1004,0.2061,0.3677)\\&= 1-(0.0013,0.0116,0.0705)=(0.9295,0.9884,0.9987)\end{aligned}$$

i.e., defuzzified value = (0.9295 + 0.9884 + 0.9987)/3 = 0.9722.

4.2.2. Fuzzy Probability of Opportunistic Behaviors

Analogously, with reference to Figure 4, either the violation of commitment or the evasion and refusal to adapt to change would cause opportunistic behaviors. The fuzzy probability of opportunistic behaviors is therefore expressed as opportunistic behaviors = violation of commitment ∪ evasion and refusal to adapt to change:

$$\begin{aligned}&\widetilde{P_{\text{Opportunistic behaviors}}}\\&= 1-\left(1-\widetilde{P_{\text{Violation of commitment}}}\right)\otimes\left(1-\widetilde{P_{\text{Evasion and refusal to adapt change}}}\right)\\&= 1-[1-(0.9231,0.9789,0.9960)]\otimes[1-(0.5961,0.7424,0.8574)]\\&= 1-(0.0040,0.0211,0.0769)\otimes(0.1426,0.2576,0.4039)\\&= 1-(0.0006,0.0060,0.0310)=(0.9690,0.9940,0.9994)\end{aligned}$$

i.e., defuzzified value = (0.9690, 0.9946, 0.9994)/3 = 0.9876.

4.2.3. Fuzzy Probability of Contract Incompleteness

Similarly, either ambiguity, deficiency, or inconsistency of a PPP contract would stimulate the contract incompleteness factor. Thus, the fuzzy probability of contract incompleteness is expressed as contract incompleteness = ambiguity ∪ deficiency ∪ inconsistency:

$$\begin{aligned}&\widetilde{P_{\text{Contract incompleteness}}}=1-\left(1-\widetilde{P_{\text{Ambiguity}}}\right)\otimes\left(1-\widetilde{P_{\text{Deficiency}}}\right)\otimes\left(1-\widetilde{P_{\text{Inconsistency}}}\right)\\&=1-[1-(0.8767,0.9630,0.9920)]\otimes[1-(0.5528,0.7705,0.8972)]\otimes[1-(0.2443,0.4460,0.6165)]\\&=1-(0.0080,0.0370,0.1233)\otimes(0.1208,0.2295,0.4472)\otimes(0.3835,0.5540,0.7557)\\&=1-(0.0003,0.0047,0.0417)=(0.9583,0.9953,0.9997)\end{aligned}$$

i.e., defuzzified value = (0.9583 + 0.9953 + 0.9997)/3 = 0.9844.

4.2.4. Fuzzy Probability of PPP Dispute

The likelihood of the fuzzy occurrence of a PPP dispute is expressed as follows: PPP dispute = project uncertainty ∩ opportunistic behaviors ∩ contract incompleteness, which means that the intersection of project uncertainty, opportunistic behaviors, and contract incompleteness would result in a PPP dispute. The fuzzy probability of a PPP dispute is as follows:

$$\begin{aligned}&\widetilde{P_{\text{PPP dispute}}}=\widetilde{P_{\text{Project uncertainty}}}\otimes\widetilde{P_{\text{Opportunistic behaviors}}}\otimes\widetilde{P_{\text{Contract incompleteness}}}\\&=(0.9295,0.9884,0.9987)\otimes(0.9690,0.9946,0.9994)\otimes(0.9583,0.9953,0.9997)\\&=(0.8631,0.9784,0.9979)\end{aligned}$$

i.e., defuzzified value = (0.8631 + 0.9784 + 0.9979)/3 = 0.9464.

Figure 7 presents the likelihood of the fuzzy occurrence of a PPP dispute, the dispute components, and the dispute factors.

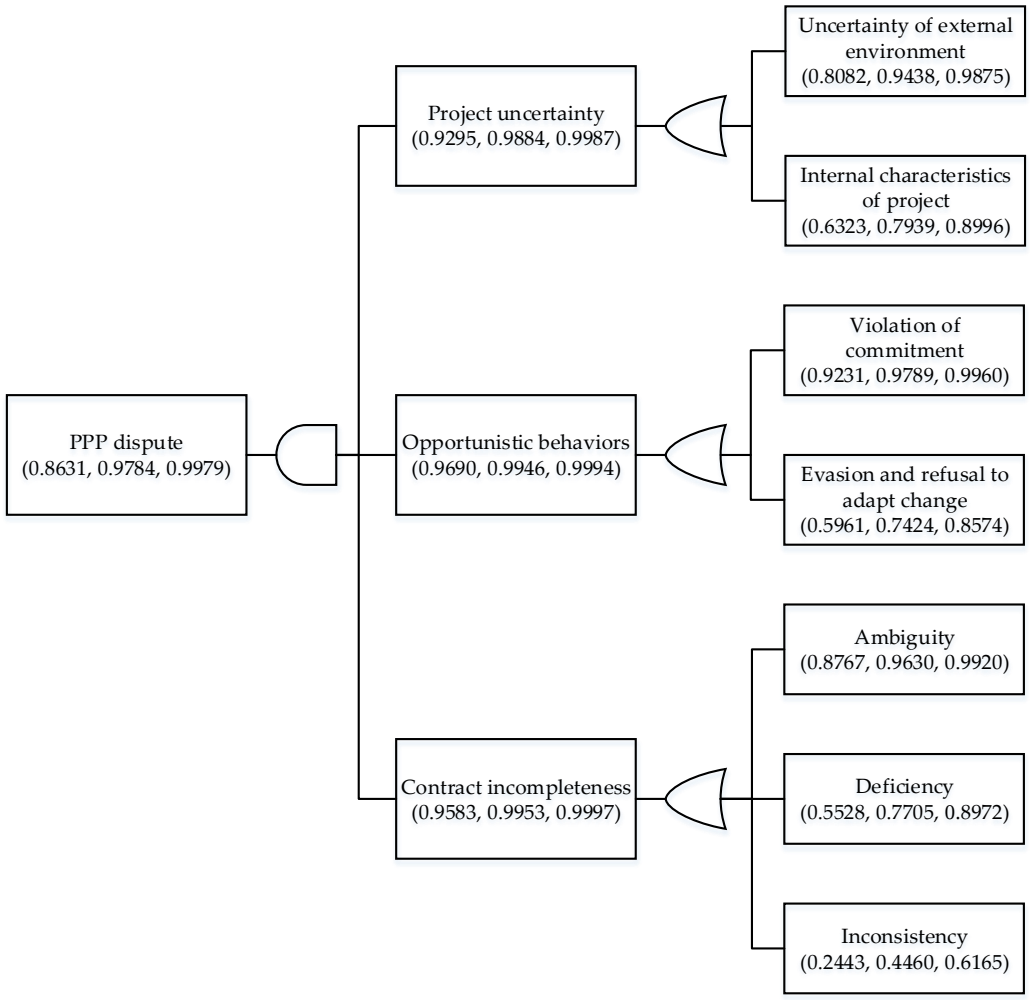

Figure 7. Fuzzy probabilities of a PPP dispute.

4.3. Discussions

For a clearer comparison and analysis, the defuzzified likelihood of a PPP dispute components and dispute factors contributing to the PPP dispute are presented in Figure 8. The defuzzified values of the top event (PPP dispute) and dispute components (project uncertainty, opportunistic behaviors, and contract incompleteness) are marked in italics and bold.

First, the likelihood of the fuzzy occurrence of a PPP dispute (top event in the FT) is 0.9464, which indicates that a dispute is inevitable in PPP projects. Although most previous studies shared the view that PPP disputes are common and inevitable due to the characteristics of a long-term agreement, the high value, and the multiple stakeholders [14–16], the findings based on the FT model provide an empirical analysis to support this perception. In this regard, our findings in fact provide a positive direction for PPP management. The inevitability of PPP disputes suggests that both public and private practitioners should be proactive in dispute prevention during the whole life cycle of a PPP project. An efficient mechanism of preventing PPP disputes is crucial to ensuring the success of a PPP project and reducing losses.

Second, Figure 8 presents the fuzzy probability values of the three basic components (project uncertainty, opportunistic behaviors, and contract incompleteness): 0.9722, 0.9876, and 0.9844, respectively. The results indicate that opportunistic behavior is the dominant driver of PPP disputes. In PPP projects, governments and private partners are in pursuit of different objectives and values. Hence, one party may behave opportunistically to increase their own interests or to reduce the other party's revenue. As Williamson [66] explained,

opportunism refers to a lack of honesty or candor. For example, to attract a private partner to participate in a PPP project, the public sector may conceal its true financial affordability and make excessive guarantees. Once a revenue shortage appears, the public sector would reject payment of fees or subsidies to the private sector. Additionally, the results revealed that contract incompleteness is a relatively significant PPP dispute contributor. Due to information asymmetry and bounded rationality of humans, contracts are invariably incomplete [67]. Consequently, whenever unforeseeable dispute events occur ex post and are not fully explicit ex ante, such a situation predictably stimulates dispute. Therefore, efforts should be made to minimize contract incompleteness during the investigation phase before signing the contract. Finally, project uncertainty is less detrimental to PPP projects in comparison with opportunistic behaviors and contract incompleteness. The more complex the PPP project, the more uncertainty it faces. In response to the uncertainty involved in the preparation, construction, operation, and transfer stages of PPP projects, the stipulations of PPP contracts need to allow for changes when adapting to contingencies. Therefore, Cruz and Marques [68] proposed that contract flexibility can be used to cope with project uncertainty in PPPs.

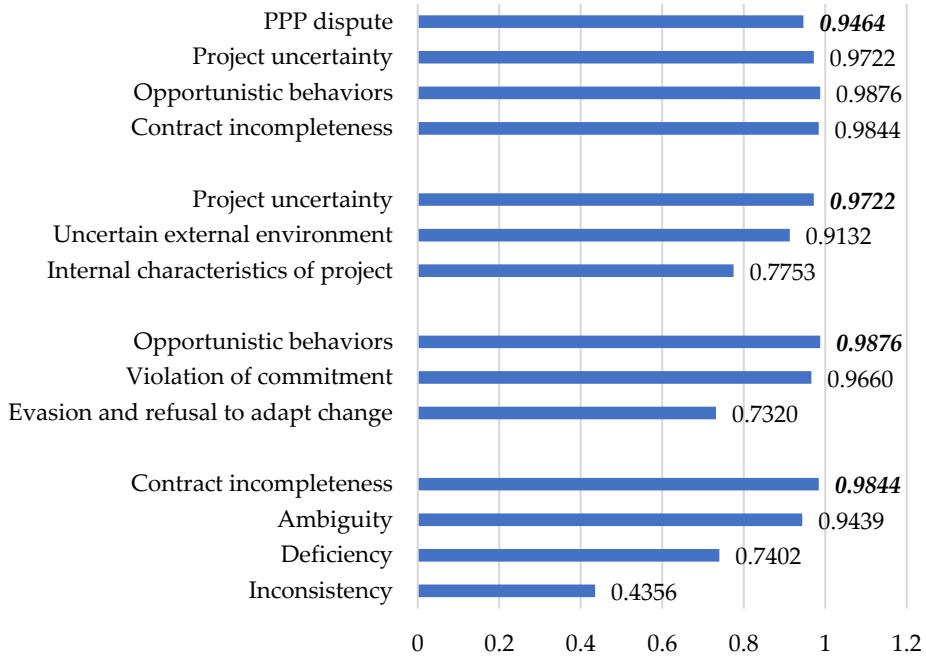

Figure 8. Defuzzified occurrence likelihood of a PPP dispute and dispute components.

Third, our evaluation of the fuzzy probability of dispute events occurring indicates that an uncertain external environment (fuzzy probability of 0.9132) is more pernicious than project internal characteristics in project uncertainty issues. Analogously, a violation of commitment (fuzzy probability of 0.9660) appears to be quite readily involved in a long-term PPP project. Ambiguity (fuzzy probability of 0.9439) is a common problem in PPP contracts.

Finally, our assessment of the likelihood of dispute events occurring illustrates that a change in regulations (PU1) and economic downturns or upturns (PU5) is most likely to result in an uncertain external environment; a breakdown in the public sector's commitment to exclusive guarantee (OV2), government payment default (OV3) or insufficient capital from the private sector (OV5), and refusal to adjust the contract price/period in response to revenue shortage (OE1) are common opportunistic behaviors in PPPs; and unclear conditions and procedures for termination (CA1) and unclear repurchasing procedures (CA4) in PPP contracts are common manifestations of contract incompleteness. The fuzzy probabilities of these dispute factors are all above 0.5.

5. Conclusions

The findings of this paper provide a number of important theoretical bases for the study of PPP disputes. First, various contributors to PPP disputes at different levels are identified. The three basic components that drive the development of PPP disputes are project uncertainty, opportunistic behaviors, and contractual incompleteness. Furthermore, they can be categorized into seven factors: uncertain external environment, internal characteristics of the project, violation of commitment, evasion and refusal to adapt to change, ambiguity, deficiency, and inconsistency. These factors are conceptualized by their respective dispute events. In this format, PPP disputes can be depicted more intelligibly. Second, the components of a PPP dispute are described under an FT structure, whereby the various contributors are combined through logic gates. This arrangement offers a holistic understanding of how the various contributors influence the formation of PPP disputes and provides an opportunity to quantify its likelihood. Then, the fuzzy set evaluation method is employed to compute the likelihood of the fuzzy occurrence of PPP a dispute. Third, with this FT framework and assessment approach, both government and private partners can identify the weakest part of a PPP project and generate the most suitable dispute prevention strategies. The findings show that opportunistic behavior is the dominant dispute inducer in PPPs.

For the policy implications of this study, the outputs empirically support disputes inevitable (with an occurrence likelihood of 0.9464) in PPP projects. Certainly, this provides a positive direction in PPP management. Both public and private practitioners should be proactive in minimizing the occurrence of disputes during a PPP project. In the preparation stage, public and private partners can use the case-based reasoning (CBR) method to retrieve similar past projects to improve the completeness of the PPP contract. In the signing stage, flexible contracts can be used to cope with project uncertainty. During the contract execution stage, Guasch and Straub [69] demonstrated that the existence of a specialized regulator can act as a barrier against opportunistic behaviors.

Additionally, this study adds significant value to enhancing empirical studies on PPPs. First, our checklist of the various contributors to the development of PPP disputes provides a solid foundation for formulating hypotheses in future empirical research. Second, the FT framework of PPP dispute provides empirical evidence for quantitative assessments of the likelihood of a dispute occurring. Essentially, the research outputs improve the chances of successfully preventing disputes in PPPs, which is vital to the sustainable development of a PPP model.

Besides the significance of the proposed FT framework and assessment approach, like any other research, this study also has some limitations. First, the sample size is relatively low; thus, the responses may not represent all the PPP experts. Second, all of the respondents came from China, which will affect the generalizability of the research findings. It is therefore suggested that future studies should interview respondents from different countries to compare the differences of PPP dispute occurrences. Finally, the dependence between occurrences of basic events (terminal events) in the FT is not considered, because the basic events are assumed independent when the FT is initially built [70]. Other approaches can be considered in conjunction with the FT analysis to make the assessment more scientifically applicable in further research. Significantly, the results of an assessment of the likelihood of a fuzzy occurrence are based on opinions provided by PPP professionals, which are inevitably influenced by human subjectiveness. The objective frequency of PPP disputes in actual cases can be investigated in future studies.

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