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Quantifying the complexity of transportation projects using the fuzzy analytic hierarchy process

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Abstract

Transportation projects are increasingly complex. A systematic approach for measuring and evaluating complexity in transportation projects is imperative. Thirty six project complexity factors were identified specifically for transportation construction. Using factor analysis, this study deduced the six components of project complexity, namely *sociopolitical*, *environmental*, *organizational*, *infrastructural*, *technological*, and *scope* complexity. The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method was employed to determine the weights of the components and parameters of project complexity. Sociopolitical complexity was the most defining component of complexity in transportation construction. A complexity level (CL) was proposed to measure the overall project complexity. The application of the proposed approach was demonstrated in a case study of three transportation projects performed by a heavy construction company. As a quantitative measure CL enables managers to better anticipate potential difficulties in complex transportation projects. As a result, scarce resources will be allocated efficiently among transportation projects in a company's portfolio.

Keywords: Complexity; Project complexity; Transportation projects; Transportation construction; Fuzzy AHP

1. Introduction

Projects are increasingly complex in today's fast changing environment. A complex project involves a multitude of activities contingent each other in various ways to achieve the project's overall outcome (Browning, 2014). Project Management Institute (PMI, 2014) stated that the causes of complexity in programs and projects could be grouped into three broad categories: human behavior, system behavior, and ambiguity. Project management has therefore encountered many difficulties due to the rapidly increasing complexity of most projects (Baccarini, 1996; Bosch-Rekveldt et al., 2011; Thomas and Mengel, 2008; Vidal and Marle, 2008; Williams, 1999). The increasing complexity could even cause a failure for projects if underestimated this complexity (Bosch-Rekveldt et al., 2011). Thus, an understanding of how to manage project complexity was crucial (Baccarini, 1996).

Without exception transportation projects have become progressively complex. The fact that many factors contribute to complexity in transportation construction, managing this complexity is not an easy task. The challenge of how to construct complex transportation projects successfully becomes more difficult. Thus, there is a need to systematically measure and evaluate complexity in transportation projects. This will help parties involved properly allocate their scarce resources in the portfolio of their transportation projects with different levels of complexity. Although many studies attempted to measure project complexity, most measures showed limitations such as: lack of reliability, non-intuitive for end-users, and/or difficult to calculate (Vidal et al., 2011a).

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This research aims at developing: (1) a hierarchical structure of complexity in transportation projects, consisting of complexity components and parameters; and (2) a Fuzzy Analytic Hierarchy Process (Fuzzy AHP) – based model to measure project complexity. Any transportation agency or heavy construction contractor usually has multiple transportation projects at any time period. Our premise is that the top management of these entities should pay more attention and prioritize resources to more complex projects. However, transportation projects may have different levels of complexity that cannot easily determined. A quantitative evaluation of project complexity within a project portfolio was promising because this evaluation resulted in not only which projects were most complex but also how complex these projects are (Vidal et al., 2011a). Project managers agreed that failure to understand the complexity of the project oft-times caused project failure (Hass, 2009). This study helps transportation agencies and heavy construction contractors quantify the complexity levels of transportation projects. When the complexity of each project can be measured, all transportation projects in a portfolio can be ranked based on their complexity levels. Consequently, top management will have more informed decisions in prioritizing projects and allocating resources for different projects. This study focused on transportation projects in the construction phase in Vietnam.

2. Previous studies

2.1. Project complexity

Literature proposed various definitions of project complexity. However, project complexity was still vaguely defined because it was not easy to describe project complexity adequately (Klir, 1985; Sinha et al., 2001). Baccarini (1996) defined project complexity as "'*consisting of many varied interrelated parts' and can be operationalized in terms of differentiation and interdependency*." This author further elaborated his proposed definition in two types of project complexity, namely organizational complexity and technological complexity. Williams (1999) specified that overall project complexity could be characterized by structural complexity (i.e. number of elements and interdependence of elements) and uncertainty (i.e. uncertainty in goals and uncertainty in methods). Geraldi and Adlbrecht (2007) divided project complexity into three groups: faith, fact, and interaction. Bosch-Rekveldt et al. (2011) developed a framework of technical, organizational, and environmental elements for the complexity of large engineering projects. Although it was difficult to understand, foresee, and control project complexity (Vidal et al., 2011a), project managers were well-prepared if project complexity could be measured. In other words, "*how organizations anticipate, comprehend and navigate complexity determines their successes and failures*" (PMI, 2013).

2.2. Project complexity factors

A review of previous studies revealed that project complexity could be characterized by a number of complexity factors. However, classifications of these factors were not consistent. Vidal et al. (2011a,b) divided project complexity factors into organizational and technological complexity factors. Bosch-Rekveldt et al. (2011) characterized project complexity in three aspects, namely technical, organizational, and environmental.

The technical aspect was an important aspect to project complexity (Bosch-Rekveldt et al., 2011). The technical aspect includes many factors contributing to project complexity such as: experience with technology (Baccarini, 1996; PMI, 2013), technological newness of the project (Dewar and Hage, 1978; Geraldi and Adlbrecht, 2007; Tatikonda, 1999; Vidal and Marle, 2008), technical risks, quality requirements (Bosch-Rekveldt et al., 2011), variety of project management methods and tools applied (Vidal and Marle, 2008), and variety of tasks (Williams, 1999). As a result, identifying technical complexity factors could help project participants to navigate project complexity.

The organizational aspect appeared to be the greatest source of project complexity (Qureshi and Kang, 2015; Vidal et al., 2011a). The organizational aspect includes many factors contributing to project complexity such as: project duration (Vidal and Marle, 2008; Xia and Lee, 2005), size of site area, interfaces between different disciplines (Bosch-Rekveldt et al., 2011), trust in project team (Bosch-Rekveldt et al., 2011; Geraldi and Adlbrecht, 2007; Vidal and Marle, 2008), trust in contractor (Bosch-Rekveldt et al., 2011; Geraldi and Adlbrecht, 2007), experience with parties involved, number of different languages (Bosch-Rekveldt et al., 2011; Geraldi and Adlbrecht, 2007), contract types, organizational risks (Bosch-Rekveldt et al., 2011), and ambiguity of project features, resources, and phases (PMI, 2013).

The environmental aspect was the other important characteristic of project complexity (Bosch-Rekveldt et al., 2011). The environmental aspect includes many factors contributing to project complexity such as: weather conditions (Bosch-Rekveldt et al., 2011; Vidal and Marle, 2008), stability of project environment, political/authority influences (Geraldi and Adlbrecht, 2007; PMI, 2013), remoteness of location (Bosch-Rekveldt et al., 2011), number of stakeholders (Baccarini, 1996; Geraldi and Adlbrecht, 2007; Vidal and Marle, 2008; Williams, 1999), variety of stakeholders' perspectives (Geraldi and Adlbrecht, 2007; PMI, 2013; Vidal and Marle, 2008), interference with existing site, risks from environment (Bosch-Rekveldt et al., 2011), and level of competition (Vidal and Marle, 2008).

2.3. Measurement of project complexity

Previous studies proposed a few models for measuring project complexity. Davies (1973), Davis (1975) and Kaimann (1974) used a coefficient of network complexity (CNC) to calculate the degree of complexity of a critical path network. Temperley (1982) suggested a measure of project complexity based on chart and relationship of activities. Nassar and Hegab (2006) developed a measure of assessing project schedules' complexity based on connectivity of activities. However, these studies focused on measuring schedule network complexity and not project complexity. Cicmil and Marshall (2005) proposed a conceptual framework for understanding the complexity of construction projects. This framework consisted of three interconnected aspects: complex processes of social interaction; flux and change – radical unpredictability of project performance; and persisting ambiguity and equivocality of performance criteria, contradictory and conflicting understanding of project success. A major drawback was that the framework did not provide a quantitative assessment of project complexity. Hass (2009) identified different aspects of project complexity and proposed a project complexity model using a systematic thinking approach, where complexity could be visualized based on a spider chart. The model was however designed to best fit projects in the business environment (Hass, 2009). Xia and Chan (2012) proposed a linear and additive model to measure complexity for building projects in China. This study may not be practically used as only six complexity measures were included in their final model. Vidal et al. (2011a) stated that despite these attempts to measure project complexity, there were concerns about the reliability of the evaluation and the applicability of the proposed models.

The need for adopting a multi-criteria decision making (MCDM) method to measure project complexity is essential. Among various MCDM methods, AHP appeared to be a viable candidate. The use of AHP preponderated in scientific publications in construction (Jato-Espino et al., 2014). In addition, Vidal et al. (2011b) confirmed that AHP was likely the most appropriate method for measuring project complexity. These authors proposed a new model using AHP method to determine project complexity index (Vidal et al., 2011a,b). Although this model solved many problems in measuring project complexity, it still had limitations. As these authors pointed out, uncertainty in judgment of the users was not considered in their model (Vidal et al., 2011b). For that reason, this research employed Fuzzy AHP to measure project complexity. Fuzzy numbers can deal with uncertainty and imprecision in pairwise comparisons in AHP (Jato-Espino et al., 2014). Detailed descriptions of Fuzzy AHP are available elsewhere (e.g., Boender et al., 1989; Buckley, 1985; Chang, 1996; Cheng, 1997; Wang and Chin, 2011).

3. Research methodology

The research framework (Fig. 1) presents processes and associated techniques used in this study. Major steps include (1) identification of project complexity factors and those specifically in transportation, (2) components and parameters of project complexity, (3) weighing the components and parameters of project complexity, and (4) measurement of transportation project complexity.

Project complexity factors were identified through literature review. The searches for relevant literature were conducted within and outside our university library databases. The searches included academic science, engineering, and business databases (e.g., LexisNexis, Engineering Village; ScienceDirect, Science Citation Index, ABI/INFORM, ProQuest; PMI Online Library) and general Internet search engines. The list of project complexity factors from literature served as a starting point to obtain input from experienced professionals to finalize project complexity factors in transportation. The first questionnaire survey was

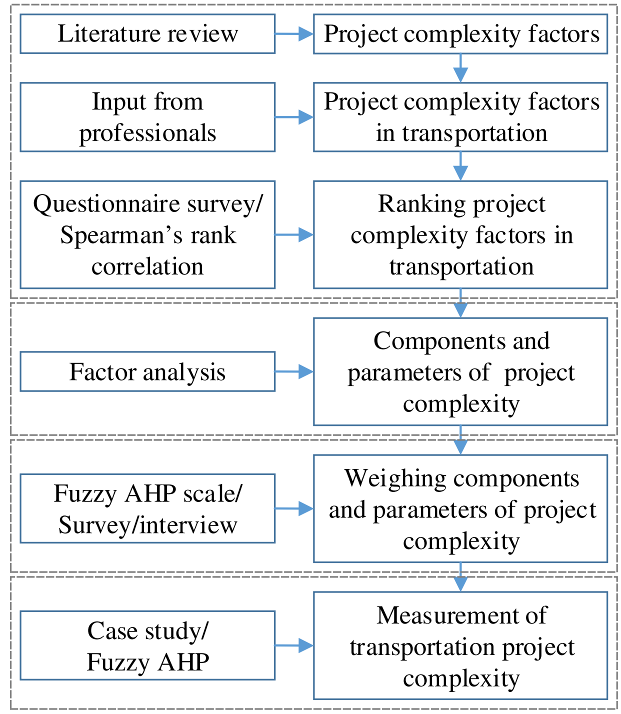

Fig. 1. Research framework.

conducted to determine the perceived relative importance of the project complexity factors. This study employed factor analysis to establish a hierarchical structure of transportation project complexity with associated components and parameters. Factor analysis was used for reducing observed and correlated variables because there were many project complexity factors involved. Factor analysis helped establish lower number of latent and unobserved factors which were relatively independent of one another.

The second survey/interview was then performed to determine the weights of these components and parameters. Fuzzy AHP was used as a MCDM method to measure transportation project complexity. This study employed Fuzzy AHP to deal with uncertainty in judgment of the practitioners and imprecision in pairwise comparisons in AHP. Fuzzy AHP is a practical method for dealing with fuzziness and uncertainty in MCDM and has huge applications in current years (Wang and Chin, 2011). Finally, this research demonstrated the application through a case study. The details are described together with research findings in the following sections.

4. Project complexity factors in transportation construction

Literature review was conducted to establish a list of 50 project complexity factors. To fit in this research context (transportation projects), these factors were reviewed and refined by a group of six professionals experienced in transportation projects through semi-structured interviews and group discussion. All professionals had at least eight years of experience in construction of transportation projects in Vietnam. Each professional was provided the 50 project complexity factors and was asked to choose which factors were applicable in transportation construction based on his/her experience. From this process, while many factors were easily agreed by six professionals to keep in the list of the project complexity factors, a few factors were chosen by some professionals but not all. They were then asked to discuss these few factors to finalize the list. As a result, 33 out of 50 factors were collectively chosen by six professionals. The professionals also suggested adding three new factors to the list, including "number of contract/work packages," "site compensation and clearance," and "geological/hydrological conditions." The final list consisted of 36 project complexity factors.

Next, a preliminary questionnaire was drafted for review/feedback from a group of 18 professionals (including the first six professionals), who had at least five years of experience in transportation construction. They worked for owners and contractors in various capacities such as project managers, functional managers, chief engineers, and project engineers. They were asked to (1) complete all questions in the preliminary questionnaire and (2) provide feedback/comments for the clarity of the survey questions. The pilot test was completed after two rounds when the factors and the structure of questionnaire were generally agreed by most participants. Thirty six factors affecting transportation project complexity were finalized and included in the final questionnaire (Table 1).

The questionnaire survey was conducted to identify the relative importance of these factors with regard to project complexity. Respondents were asked to rate the project complexity factors in a five-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"). A list of 1345 respondents, who worked in transportation projects in Vietnam, was established for the survey. The respondents were identified from the Vietnam Road and Bridge Association, Ho Chi Minh City Road, Bridge, and Port Association, and alumni networks of major transportation engineering programs. The questionnaire was either emailed or hand-delivered to the respondents. In total, 1,225 respondents received the questionnaire by emails and 120 received a hard copy. To increase the response rate, the authors used the software SmartSerialMail to personalize emails sent to each respondent.

Table 1
Ranking of project complexity factors.

Project complexity factor	Overall		Owner		Contractor	
	Mean	Rank	Mean	Rank	Mean	Rank
Site compensation and clearance	4.39	1	4.52	1	4.21	1
Qualifications required for contractors	4.29	2	4.34	2	4.21	2
Coordination of stakeholders	4.21	3	4.24	4	4.16	3
Experience expected from parties for technologies employed	4.18	4	4.25	3	4.07	5
Number of project team members	4.16	5	4.22	5	4.07	4
Market conditions	3.99	6	3.98	6	4.00	6
Number of applicable laws/regulations	3.97	7	3.95	7	4.00	7
Administrative policies/procedures	3.85	8	3.91	8	3.77	9
Geological/hydrological conditions	3.80	9	3.77	11	3.84	8
Contractual conditions	3.74	10	3.85	9	3.57	23
Project planning and scheduling	3.73	11	3.75	12	3.70	14
Local experience expected from parties	3.71	12	3.77	10	3.62	18
Diversity of project parties	3.68	13	3.66	15	3.70	12
Project duration	3.64	14	3.67	13	3.61	19
Transportation systems near project site	3.64	15	3.62	17	3.66	16
Project size in terms of capital	3.62	16	3.67	14	3.56	24
Ambiguity of project scope	3.61	17	3.51	24	3.75	10
Influence of politics	3.61	18	3.52	23	3.74	11
Environmental risks	3.61	19	3.55	21	3.69	15
Local climatic conditions	3.60	20	3.53	22	3.70	13
Local construction materials	3.59	21	3.60	19	3.59	21
Technological newness of the project	3.54	22	3.62	18	3.43	28
Participation of utility authorities/companies	3.54	23	3.60	20	3.46	25
Organizational risks	3.54	24	3.47	26	3.64	17
Variety of technologies employed	3.53	25	3.49	25	3.57	22
Number of contract/work packages	3.51	26	3.66	16	3.30	31
Number of stakeholders	3.45	27	3.47	27	3.43	29
Construction risks	3.41	28	3.47	28	3.31	30
Form of contract	3.40	29	3.38	29	3.43	27
Number of different languages	3.34	30	3.16	33	3.59	20
Construction site	3.27	31	3.14	34	3.46	26
Level of quality requirements	3.18	32	3.17	32	3.20	32
Number and diversity of activities	3.15	33	3.17	31	3.11	33
Size of the project site (in area)	3.08	34	3.21	30	2.90	36
Competition among contractors	3.03	35	2.99	35	3.10	34
Level of health, safety, and environmental requirements	2.99	36	2.92	36	3.08	35

After three months, with a reminder after one month from the first contact, 316 responses (249 emails/soft copies and 67 hard copies) were received with the overall response rate of 23.5%. The responses from professionals not working for either owner or contractor or less than five years of experience were excluded. Only responses from professionals working for owners and contractors were considered because this study focused on the construction phase in which design professionals might not have direct and substantial involvement. The authors also endeavored to identify incomplete responses where some questions in the questionnaire were left unanswered. Through these processes, the authors eliminated 168 potentially invalid responses from 316 responses received. Finally, 148 responses were considered valid for further analyses. The reliability test yielded a Cronbach's alpha coefficient of internal consistency value of 0.84 (>0.80), which is considered reliable.

Out of 148 responses, 87 (58.8%) and 61 (41.2%) were from professionals working for owners and contractors, respectively. In terms of experience, 42.5%, 51.4%, and 6.1% had 5–10 years of experience, 10–20 years of experience, and more than 20 years of experience, respectively. In terms of position, 17.5% were senior managers, 49.3% were functional managers and project managers, 29.1% were line managers, engineers, and projects team members, and 4.1% were others. Lastly, 35.8% were involved in transportation projects with less than US$10 million in budget while 64.2% were involved in projects with budget of US$10 million or higher.

In order to identify complexity factors of transportation projects, this study investigated the perceptions of professionals working for owners and contractors as to project complexity. The rating of respondents on the five-point scale was used to determine the mean of each complexity factor and to rank the factors (Table 1). The top five factors seemed consistent between the two groups. "Site compensation and clearance" and "qualifications required for contractors" were ranked first and second for both groups of respondents working for owners and contractors. It should be noted that "site compensation and clearance" was a factor added by the group of the six professionals discussed previously.

Spearman's coefficient of rank correlation (r_s) was used to check if there was a correlation between the ranking orders of the two groups. The t-test was also employed to examine whether mean values of each factor rated by the two groups were different. The Spearman's rank correlation coefficient (r_s) between owner and contractor was 0.790 with the significance level of 1% (two-tailed). This implied that there was a strong agreement between two groups on ranking the project complexity factors. Because Spearman's rank correlation test did not suggest if there was a difference in assessing an individual factor, t-test was performed to evaluate the differences of mean values of the factors between the two groups. The results of t-test showed that there was no significant difference in the perceptions of the two groups at the significance level of 5% except factor "number of different languages" (ranked 30 overall, Table 1).

5. The components and parameters of transportation project complexity

This research used factor analysis with the varimax rotation method to uncover the underlying relationships among the complexity factors and to draw a hierarchical structure of project complexity. The hierarchical structure of project complexity included components, which were groupings extracted from factor analysis, and parameters, which were project complexity factors in these components. According to the latent root criterion, all extracted components must have eigenvalues more than one. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy should be greater than 0.5. Bartlett's test of sphericity which indicates whether the correlation matrix is not an identity matrix must be significant at 0.05. As a rule of thumb, factor loadings less than 0.5 are suppressed. Additionally, the communalities of all factors included in factor model must be more than 0.5 to signify the reliability of the model.

The top 26 project complexity factors having the overall mean scores more than 3.50 in Table 1 were selected for factor analysis. Since the communality values of these 26 factors were greater than 0.5, all of them were appropriate for the next steps of factor analysis. The KMO measure of sampling adequacy was satisfactory at the value of 0.804. Bartlett's test of sphericity having the significance level of 0.000 with chi-square value of 831.816 indicated that the correlation matrix was not an identity matrix (Table 2). Thus, a factor analysis was applicable.

Table 3 presents the results of the factor analysis using the varimax rotation method. The factor analysis extracted six components which total amount of variance explained was two third (66.781%, Table 3). As a summary of this factor analysis, Fig. 2 presents the "cube" of project complexity in transportation. The six components were named as *sociopolitical complexity* (C1); *environmental complexity* (C2), *organizational complexity* (C3), *infrastructural complexity* (C4); *technological complexity* (C5); and *scope complexity* (C6). As a metaphor, they present the six faces of the cube of project complexity (Fig. 2). In addition, the parameters, or sub-components, were the project complexity factors grouped in each of the six components. Each parameter is referred as Cij where Ci is component number and j is its standing number within its component. For example, "variety of technologies employed" (C51) is in component C5 (*technological complexity*) and is listed the first in this component. The following is brief discussion of these components and parameters of project complexity.

Table 2
KMO and Barlertt's test.

Kaiser-Meyer-Olkin measure of sampling adequacy		0.804
Bartlett's test of sphericity	Approx. chi-square	831.816
	df	153.000
	Sig.	0.000

Table 3
Results of the factor analysis using the varimax rotation method.

Project complexity factor	Factor loading	Eigenvalue	Cum. variance (%)
Component 1		5.165	14.027
Administrative policies/procedures	0.768		
Number of applicable laws/regulations	0.718		
Local experience expected from parties	0.694		
Influence of politics	0.687		
Component 2		1.765	26.325
Local climatic conditions	0.763		
Geological/hydrological conditions	0.696		
Environmental risks	0.643		
Component 3		1.491	38.604
Contractual conditions	0.754		
Number of contract/work packages	0.736		
Coordination of stakeholders	0.616		
Project planning and scheduling	0.587		
Component 4		1.369	49.980
Site compensation and clearance	0.789		
Transportation systems near project site	0.703		
Qualifications required for contractors	0.658		
Component 5		1.202	59.090
Variety of technologies employed	0.860		
Technological newness of the project	0.845		
Component 6		1.030	66.781
Ambiguity of project scope	0.729		
Project size in terms of capital	0.568		

5.1. Sociopolitical complexity

Sociopolitical complexity was characterized by four parameters: administrative policies/procedures, number of applicable laws and regulations, local experience expected from parties, and influence of politics. Administrative policies/procedures were regulatory processes required before and during construction of transportation projects. Slow permits by government agencies was a delay factor in construction projects in Thailand (Ogunlana et al., 1996). Obviously, sociopolitical factors affected project implementation and increased project complexity. Nguyen et al. (2004) found that legal and institutional framework was a major problem for large construction projects in Vietnam. Laws and regulations applied to transportation projects were still confusing and ambiguous. As a result, the implementation of transportation projects encountered many difficulties. As transportation projects typically spread out in large area and interfaced with various stakeholders, local experience and political influences contributed to project complexity. Kaming et al. (1997) found that lack of experience of project location was an important cause of problems in Indonesia. Significant political/authority influences was the third most defining characteristic of project complexity (PMI, 2013). Thus, measuring sociopolitical complexity helps estimate the level of complexity of transportation projects.

5.2. Environmental complexity

Environmental complexity was an important component of project complexity in construction of transportation projects. Most construction activities in transportation projects were exposed to weather. Thus, local climatic conditions could have an impact on construction performance. Adverse weather could cause inefficiencies, cost overruns, and/or complete suspension of construction activities (El-Rayes and Moselhi, 2001). In recent years, due to complex topographical, geological, and hydrological conditions, transportation projects in Vietnam frequently encountered significant delays, cost overruns, and poor quality. Geographic conditions and weather conditions were problems experienced during transportation construction in Indonesia (Abednego and Ogunlana, 2006). Unforeseen site conditions and subsurface conditions of geology and ground water were also found as critical problems in Thailand (Ghosh and Jintanapakanont, 2004). Also, the development of transportation projects can cause a variety of environmental risks (noise, pollution, etc.). The existence of these risks obviously contributed to project complexity. Xia and Chan (2012) found that “geological condition” and “neighboring environment” were in the top six complexity factors for building projects in China.

5.3. Organizational complexity

Organizational issues undoubtedly affect the complexity of transportation projects. Vidal et al. (2011a) concluded that organizational complexity was the greatest source of complexity for today’s projects and project management. The organizational complexity was characterized by four parameters: contractual conditions, number of contract/work packages, coordination of stakeholders, and project planning and scheduling. Contractual conditions dictated how project parties played to deliver a transportation project. A complex project typically has multiple contracts and stakeholders (Ghosh and Jintanapakanont, 2004). The number of contract/work packages determined the size of each work package and the number, specialties, and experience of contractors involved in a project. The coordination of various stakeholders, both internal and external, could cause project complexity. “Multiple stakeholders” was the top defining characteristic of complexity in projects (PMI, 2013). Finally, complexity required in project planning and scheduling contributes to project complexity. Schedule management played a significant role in the performance of highway construction projects in Thailand (Meeampol and Ogunlana, 2006). Improper planning was the first cause of delays in construction in Malaysia (Sambasivan and Soon, 2007).

5.4. Infrastructural complexity

Infrastructural complexity was a critical component of complexity in transportation projects. Site compensation and clearance was a process in which a governmental agency negotiated with property owners to acquire land and obtain a right of way for a transportation project. Site compensation and clearance was the most complexity factor (Table 1). This was because of land ownership issues and the gap between market price and regulated price for site compensation in Vietnam. It should be noted that private ownership of land has not been permitted in Vietnam for more than 40 years (“ownership of a

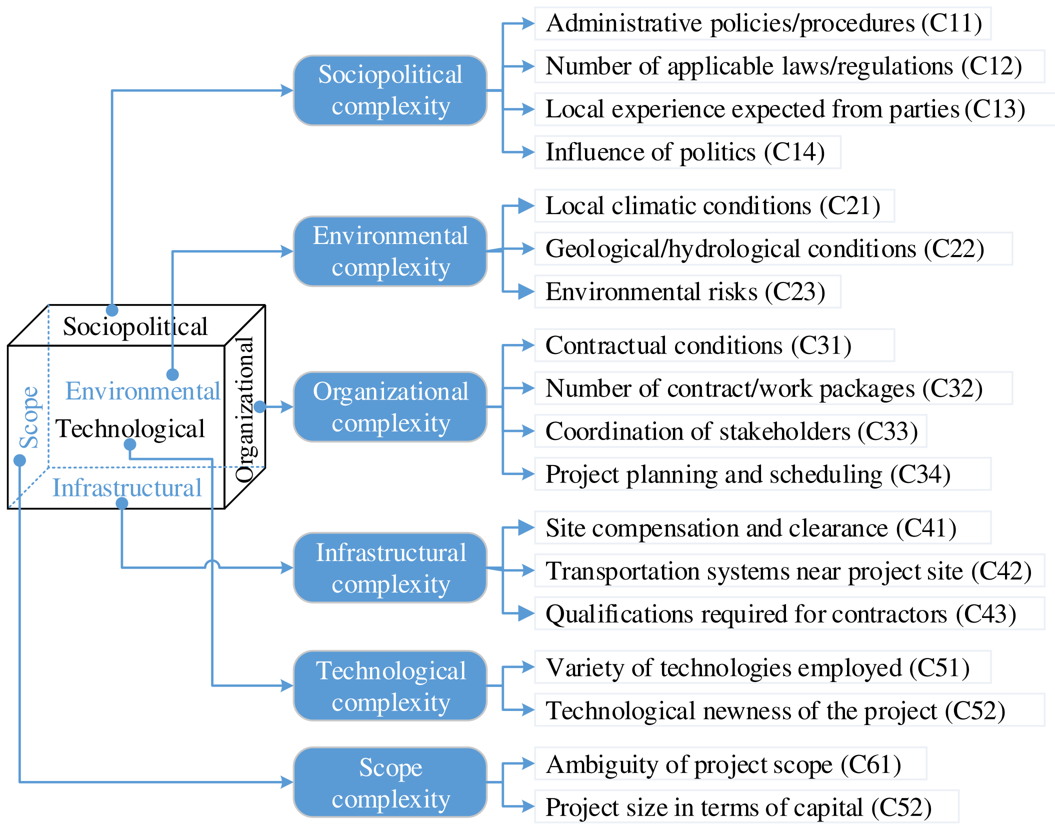

Fig. 2. The “cube” of project complexity in transportation construction.

right to use land” instead). Many transportation projects could be implemented slowly and costly when the project site was not ready and was protested by local communities. Transportation systems were another factor to characterize project complexity as they played a critical role in delivering equipment and materials to construction sites. In remote and isolated areas, development and maintenance of temporary road systems for construction activities were costly. Poor site access and availability was in the top ten problems in major construction projects in Thailand (Toor and Ogunlana, 2008) Lastly, qualifications required for contractors, the required level of experiences, capacities, capabilities, etc. from potential contractors to be eligible for working in a project, were another infrastructural complexity factor as high-performing contractors were not always available. Sambasivan and Soon (2007) identified that inadequate contractor experience was the third factor adversely affecting projects in Malaysia.

5.5. Technological complexity

Technological complexity was characterized by variety of technologies employed and technological newness of the project. These factors were critical to develop transportation systems such as: bridges, highways, and tunnels. Variety of technologies employed was the number and diversity of technologies used in a transportation project. The possession and deployment of technology were always problematic in emerging economics like Vietnam. Though technology transfer from developed world in transportation projects increasingly took place, the continuing issue was how to adopt those technologies in the local construction conditions to fully utilize them (Le-Hoai et al., 2008). PMI (2013) presented that the “use of a technology that is new to the organization” and “use of a technology that has not yet been fully developed” were in the top ten characteristics of project complexity. “Construction method” was ranked second among the complexity factor in building projects (Xia and Chan, 2012). It was a significant factor affecting cost and time performance on highway construction projects in Thailand (Meeampol and Ogunlana, 2006).

5.6. Scope complexity

Project scope complexity determined project complexity. The “ambiguity of project scope” and “project size in terms of capital” were the two factors attributable to scope complexity. Large transportation projects in Vietnam had difficulties in defining project scope due to limited experience of involved parties. Poorly-defined project scope caused various problems in downstream phases, i.e. construction. The ambiguity of project scope can cause design changes during construction. “Design changes” was ranked first in all three categories, namely importance, frequency, and severity, among the causes of delays in construction in Indonesia (Kaming et al., 1997). Ambiguity, consisting of uncertainty and emergence, was one of the three categories of complexity suggested by PMI (2014). In addition, "ambiguity of project features, resources, phases, etc." was ranked second in the most defining characteristics of complexity in projects (PMI, 2013). Cicmil and Marshall (2005) suggested that the ambiguity and equivocality of project performance criteria was one of the three aspects of complexity in construction projects.

6. Weighing the components and parameters of project complexity

The second questionnaire was designed to determine the weights for components and parameters of project complexity. The calculation of weights was based on experts' judgments according to a fuzzy nine-point scale (Table 4). This research employed Fuzzy AHP scale using triangular fuzzy numbers proposed by Tesfamariam and Sadiq (2006), which was an extension of the original nine-point scale proposed by Saaty (1980). A group of 23 professionals, who had extensive experience in construction of transportation projects, were first identified. They were invited to rate pairwise comparisons for criteria and parameters of project complexity. Though face-to-face interview was preferred, the respondents could choose to answer the questionnaire themselves. All the professionals had more than eight years of experience in construction of transportation projects, in which four of them had 8–10 years of experience, 11 of them had 11–15 years of experience, five had 16–20 years of experience, and three had more than 20 years of experience. Seven, thirteen, and three of them were senior managers, functional/project managers, and project engineers, respectively. Fig. 3 shows an illustrative partial pairwise comparisons completed by a "hypothetical" respondent. For four parameters in sociopolitical complexity (C1), six pairwise comparisons have to be rated by the professionals (Fig. 3).

To determine the weights of the components and parameters of project complexity, this research took the following sub-steps: (1) checking the consistency of the experts' judgments; (2) combination of experts' judgments; (3) defuzzification; and (4) calculation of the weights. These sub-steps are discussed below.

6.1. Consistency verification

The consistency ratio (CR) is an important measure of consistency for pairwise comparisons of the experts' judgments. CR is determined by Eq. (1) as proposed by Saaty (1980):

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

Where CI = consistency index; n = size of matrixes; λ_{max} = max (n); RI = random index. Saaty (1980) proposed the random index RI based on the size of matrixes n (Table 5). CR should not be more than 10% (Saaty, 1980). If CR is greater than 10%, the inconsistency in comparisons in the decision making matrix is unacceptable. In that case, as suggested by Saaty (2005), we can identify which judgment is the most inconsistent and determine a range of values this inconsistent judgment can be varied to increase consistency. Finally, the respective expert will be contacted again to review their comparisons (Saaty, 2005). If the resulted CR is still too large, the judgment will be excluded (Saaty and Kearns, 1985).

The CRs for 23 judgments were calculated. The judgments of two experts were identified inconsistent as their CRs were greater than 10% (about 20%). The two experts were asked to review their judgments. However, they still kept their original judgments and therefore, these two judgments were excluded. Finally, this study used the remaining 21 responses having CRs less than 10%. The CRs for the combined judgment of the 21 responses were also checked. These CRs were less than the threshold of 10% (Table 6).

6.2. Combination of experts' judgments

Using the geometric mean method (Saaty, 2008), this research combined all experts' judgments to be a general judgment. This general judgment could represent the opinion of the entire group of experts for the multiple criteria decision. The geometric mean method could be used to calculate triangular fuzzy numbers from the judgments of experts as Eq. (3) (Buckley, 1985):

$$\overline{J_{ij}} = \left(l_{ij}, m_{ij}, u_{ij}\right) : l_{ij} \le m_{ij} \le u_{ij}; l_{ij}, m_{ij}, u_{ij} \in \left[\frac{1}{9}, 9\right] \tag{3}$$

$$l_{ij} = \min\left(B_{ijk}\right) \tag{4}$$

$$m_{ij} = \sqrt[n]{\prod_{1}^{n} B_{ijk}} \tag{5}$$

$$u_{ij} = \max\left(B_{ijk}\right) \tag{6}$$

Where B_{ijk} = pairwise comparison between criteria i and j evaluated by the k^{th} expert.

Table 4
Fuzzy AHP scale.

Traditional AHP scale	Fuzzy AHP scale	Definition
1	(1, 1, 1)	Equal complexity
3	(3-Δ, 3, 3 + Δ)	Slightly more complexity
5	(5-Δ, 5, 5 + Δ)	More complexity
7	(7-Δ, 7, 7 + Δ)	Much more complexity
9	(9-Δ, 9, 9 + Δ)	Extremely more complexity
2, 4, 6, 8	(x-Δ, x, x + Δ)	Intermediate values between two adjacent judgments

	Extremely more complex		Much more complex		More complex		Slightly more complex		Equally complex		Slightly more complex		More complex		Much more complex		Extremely more complex	
Criteria/Components																		
Sociopolitical complexity (C1)	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Environmental complexity (C2)
Sociopolitical complexity (C1)	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	Organizational complexity (C3)
…	…																	…
Technological complexity (C5)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐	Scope complexity (C6)
Parameters of Sociopolitical Complexity (C1)																		
Administrative policies/procedures	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐	Number of applicable laws/regulations
Administrative policies/procedures	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local experience expected from parties
Administrative policies/procedures	☐	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐	☐	Influence of politics
Number of applicable laws/regulations	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local experience expected from parties
Number of applicable laws/regulations	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	Influence of politics
Local experience expected from parties	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐	Influence of politics
Parameters of Environmental Complexity (C2)																		
…	…																	…

Fig. 3. Partial example of pairwise comparisons.

Noticeably, Meixner (2009) reminded that using minimum and maximum operations above is not appropriate if the evaluations are inhomogeneous. The whole span of fuzzy numbers gets big when one or a few experts provide extreme values of l_{ijk} and/or u_{ijk}. The geometric mean method is therefore also used to calculate two remaining fuzzy numbers l_{ijk} and u_{ijk}. As a result, the judgments of experts are combined as Eq. (7) (Meixner, 2009):

$$l_{ij} = \left(\prod_{k=1}^{k} l_{ijk}\right)^{\frac{1}{k}};\; m_{ij} = \left(\prod_{k=1}^{k} m_{ijk}\right)^{\frac{1}{k}};\; u_{ij} = \left(\prod_{k=1}^{k} u_{ijk}\right)^{\frac{1}{k}} \quad (7)$$

Where (l_{ijk}, m_{ijk}, u_{ijk}) = triangular fuzzy numbers evaluated by the k^{th} expert.

6.3. Defuzzification

The defuzzification process is to convert the fuzzy numbers in pairwise comparison matrixes into real numbers. The α-cut and λ were used to represent the degree of confidence and attitude towards risk of the decision maker, respectively (Deng, 1999). Both α-cut and λ carry a value from 0 to 1, where 0.5 shows the average degree. A greater α-cut shows a more confidence of the decision maker while a greater λ shows a more optimistic view of the decision maker. In this study, the defuzzification process is carried out according to Eqs. (8), (9), (10), and (11) as follows (Liou and Wang, 1992):

$$Z_\alpha = \begin{pmatrix} \left[z^\alpha_{11l}, z^\alpha_{11r}\right] & \left[z^\alpha_{12l}, z^\alpha_{12r}\right] & \cdots & \left[z^\alpha_{1ml}, z^\alpha_{1mr}\right] \\ \left[z^\alpha_{21l}, z^\alpha_{21r}\right] & \left[z^\alpha_{22l}, z^\alpha_{22r}\right] & \cdots & \left[z^\alpha_{2ml}, z^\alpha_{2mr}\right] \\ \cdots & \cdots & \cdots & \cdots \\ \left[z^\alpha_{n1l}, z^\alpha_{n1r}\right] & \left[z^\alpha_{n2l}, z^\alpha_{n2r}\right] & \cdots & \left[z^\alpha_{nml}, z^\alpha_{nmr}\right] \end{pmatrix} \quad (8)$$

$$z^\lambda_{ij\alpha} = \lambda . z^\alpha_{ijr} + (1-\lambda) . z^\alpha_{ijl};\ \lambda \in [0, 1] \quad (9)$$

$$z^\alpha_{ijl} = \left(m_{ij} - l_{ij}\right) . \alpha + l_{ij} \quad (10)$$

$$z^\alpha_{ijr} = u_{ij} - \left(u_{ij} - r_{ij}\right) . \alpha \quad (11)$$

In this research, the matrixes of fuzzy numbers were converted into interval matrixes with the average degree of confidence (α = 0.5) by using Eqs. (10) and (11). Then, interval matrixes were converted into matrixes of real numbers with the average degree of attitude towards risk (λ = 0.5) by using Eq. (9). Table 7 presents the result of this defuzzification process.

Table 5
Random indexes (RI).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 6
Consistency ratios for the combined judgment.

Matrix level I	Matrixes level II					
C	C1	C2	C3	C4	C5	C6
6 × 6	4 × 4	3 × 3	4 × 4	3 × 3	2 × 2	2 × 2
0.011	0.010	0.000	0.001	0.002	0.000	0.000

Table 7
Result of defuzzification.

Component ref.	C1	C2	C3	C4	C5	C6
C1	1.00	4.53	1.30	0.97	1.97	1.57
C2	0.22	1.00	0.60	0.37	0.80	0.88
C3	0.77	1.67	1.00	0.79	1.23	1.24
C4	1.03	2.71	1.27	1.00	2.06	2.00
C5	0.51	1.26	0.81	0.49	1.00	1.07
C6	0.64	1.13	0.81	0.50	0.93	1.00

Finally, sensitivity analysis was also conducted to examine how sensitive the weights of the six components were when the degree of confidence (α-cut) changes from 0 to 1 with different cases of attitude towards risk of the decision maker (λ) such as: pessimistic (λ = 0), moderate (λ = 0.5), and optimistic (λ = 1). Sensitivity analysis provides a decision maker with a better understanding of his/her decision making. Fig. 4 demonstrates the result of sensitivity analysis in case of the moderate attitude towards risk (λ = 0.5). The weights were not sensitive to the degree of confidence α-cut for λ = 0.5 (Fig. 4).

6.4. Calculation of the weights

After the defuzzification, the real numbers were used to calculate the weights of the components and parameters of project complexity. This study chose the average degree of confidence and average attitude towards risk of the decision maker (α = 0.5; λ = 0.5) to determine the weights. This was acceptable as these weights were not sensitive to α-cut as previously discussed (Fig. 4). Table 8 summarizes the weights of the components and parameters of complexity in transportation projects.

The results revealed that sociopolitical complexity (C1) was the most defining component of complexity in transportation projects in Vietnam (Table 8). Transportation projects in Vietnam have been facing many problems relating to sociopolitical issues such as ambiguous administrative policies and procedures and conflicting regulations and standards. Bureaucracy and fraudulent practices/kickbacks in large projects have been publicly recognized in Vietnam (Nguyen et al., 2004). In addition, site

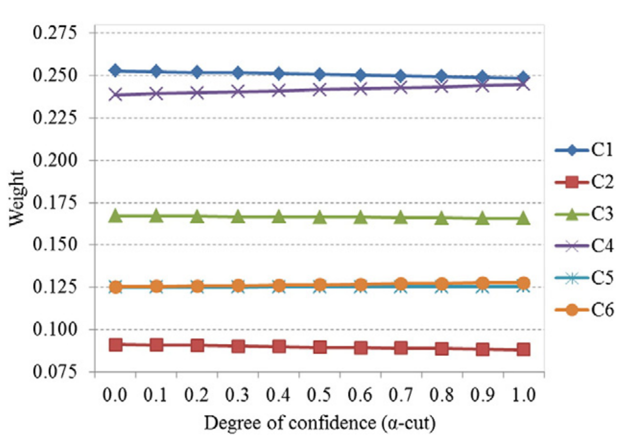

Fig. 4. Sensitivity analysis for the components' weights.

Table 8
The weights of the components and parameters of project complexity.

Criteria ref.	Parameter ref.	Weight		Overall weight (W_{ij})	Rank	
		C_i	C_{ij}		C_i	C_{ij}
C1		0.251			1	
	C11		0.220	0.055		8
	C12		0.293	0.073		3
	C13		0.228	0.057		6
	C14		0.260	0.065		5
C2		0.090			6	
	C21		0.331	0.030		15
	C22		0.427	0.038		13
	C23		0.243	0.022		18
C3		0.166			3	
	C31		0.263	0.044		11
	C32		0.169	0.028		17
	C33		0.326	0.054		9
	C34		0.242	0.040		12
C4		0.242			2	
	C41		0.671	0.162		1
	C42		0.126	0.030		16
	C43		0.204	0.049		10
C5		0.125			5	
	C51		0.544	0.068		4
	C52		0.456	0.057		7
C6		0.127			4	
	C61		0.751	0.095		2
	C62		0.249	0.032		14

compensation and clearance (C41) was as the most critical parameter of project complexity (Table 7). Slow site clearance and unsatisfactory site compensation were identified as the major causes of interruptions in large construction projects in Vietnam for years (Nguyen et al., 2004). The highest weight of this parameter was also in line with our findings from the first questionnaire survey (Table 1).

7. Measurement of complexity in transportation projects

7.1. Project complexity measure

This research proposed a distinctive scale to evaluate the parameters of project complexity in a given transportation project. That is, a scale of eleven points adapted from Satmetrix (2003) was proposed to measure complexity for each parameter. The scale is from "0 = extremely low" to "10 = extremely high", where "5 = neutral" (Fig. 5). This distinctive scale enables participants to provide a complexity score for each parameter in their project in a consistent manner.

Finally, the complexity level (CL) was proposed as an overall project complexity measure. CL carries a value from 0 to 10, where higher value of CL shows higher project complexity. CL is determined as in Eq. (12):

$$CL = \sum K_{ij} \times W_{ij} \tag{12}$$

Where K_{ij} = complexity score of parameter C_{ij}; W_{ij} = overall weight of parameter C_{ij}. K_{ij} is rated by professionals directly involved in a project under assessment. W_{ij} is the weights of the

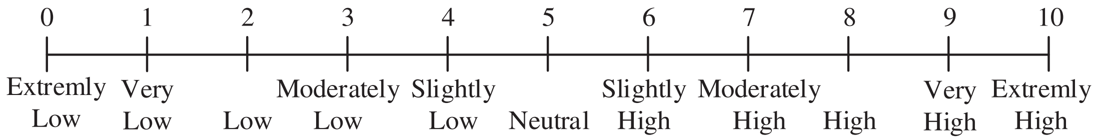

Fig. 5. Project complexity scale K.

complexity parameters in transportation projects as shown in Table 8.

7.2. Case study

This section demonstrates the measurement of project complexity in transportation construction with the use of the Fuzzy AHP method. Three transportation projects under construction by a heavy construction company in Vietnam were selected as a case study. Table 9 presents the profile of the three projects. Projects 1 and 2 were located in the North while project 3 was located in the Central of Vietnam. Project 1 was financed by private in the form of build-transfer (BT). The company was compensated by public land instead of cash for the expenses of this project in a governmental “land-for-infrastructure swap” program. Projects 2 and 3 were financed by public. Projects 2 and 3 had price adjustment contracts between government bodies and this company. Under this adjustable price form, unit prices may be adjusted for market fluctuation.

Table 9
Profile of three demonstrative projects.

Project ref.	Project type	Project finance	Contract form	Project cost (million USD)
Project 1	Highway	Public-private partnership	Build-transfer	303.7
Project 2	Highway	Public	Price adjustment	6.7
Project 3	Bridge and highway	Public	Price adjustment	11.2

Table 10
Complexity scores.

No.	Project complexity criteria/parameter	Score ref. K_{ij}	Complexity scores		
			Project 1	Project 2	Project 3
C1	*Sociopolitical complexity*				
C11	Administrative policies/procedures	K_{11}	9	8	2
C12	Number of applicable laws/regulations	K_{12}	9	5	2
C13	Local experience expected from parties	K_{13}	5	9	3
C14	Influence of politics	K_{14}	6	4	3
C2	*Environmental complexity*				
C21	Local climatic conditions	K_{21}	4	4	8
C22	Geological/hydrological conditions	K_{22}	8	4	7
C23	Environmental risks	K_{23}	4	4	6
C3	*Organizational complexity*				
C31	Contractual conditions	K_{31}	9	8	2
C32	Number of contract/work packages	K_{32}	3	3	2
C33	Coordination of stakeholders	K_{33}	7	3	3
C34	Project planning and scheduling	K_{34}	9	10	7
C4	*Infrastructural complexity*				
C41	Site compensation and clearance	K_{41}	9	10	2
C42	Transportation systems near project site	K_{42}	7	2	2
C43	Qualifications required for contractors	K_{43}	9	2	8
C5	*Technological complexity*				
C51	Variety of technologies employed	K_{51}	7	3	7
C52	Technological newness of the project	K_{52}	7	3	8
C6	*Scope complexity*				
C61	Ambiguity of project scope	K_{61}	8	3	2
C62	Project size in terms of capital	K_{62}	10	5	3

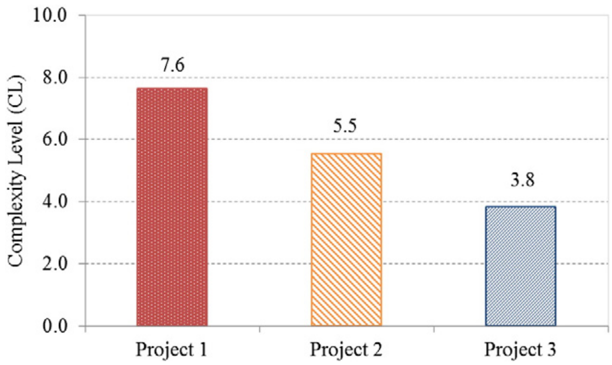

Fig. 6. Complexity levels of demonstrative projects.

A senior project director directly involved in the three projects was asked to determine the level of complexity of parameters for these projects. This project director had 17 years of experience in transportation construction. The respondent was requested to rate the complexity of parameters in the transportation projects in a scale of eleven points from "0 = extremely low" to "10 = extremely high" (Fig. 5). Table 10 presents the scores of the project complexity parameters for the three projects. These scores were used to determine the complexity level (CL) for each project based on Eq. (12). CLs for projects 1, 2, and 3 were 7.6, 5.5, and 3.8, respectively (Fig. 6). Based on the proposed project complexity K (Fig. 5), the complexity of project 1 was the highest while the complexity of project 3 was the lowest. These results implied that project 1 could to be more problematic during construction. This complexity level provided a useful quantitative measure for project managers to plan and implement their projects. These results were agreed by this construction company. The company believed that project 1 was much more complex than projects 2 and 3. In fact, they prioritized their resources for project 1 when these projects were under construction.

8. Conclusion

This research identified thirty six project complexity factors specifically for transportation construction in Vietnam through the first questionnaire survey from experienced professionals. Site compensation and clearance was the top complexity factor. Using factor analysis, this research deduced a hierarchical structure of project complexity or the "cube" of project complexity in transportation. The six faces (components) of this cube were *sociopolitical complexity*, *environmental complexity*, *organizational complexity*, *infrastructural complexity*, *technological complexity* and *scope complexity*. Each face/component is characterized by 2–4 complexity parameters.

This study also presented an approach for measuring the complexity of transportation projects. The Fuzzy AHP method was employed to determine the weights of the components and parameters of project complexity. Sociopolitical complexity was the most defining component of complexity in transportation construction. In addition, site compensation and clearance was the most critical parameter of project complexity. The highest weight of this parameter was also in line with the findings in the first questionnaire survey.

The level of project complexity could be assessed through the proposed complexity level in a range of "0 = extremely low" to "10 = extremely high". The application of the proposed approach was demonstrated in a case study of three transportation projects implemented by a heavy construction company. The results from this approach were in line with the perception of the company with regard to the relative complexity of the three projects. The complexity level is a useful indicator for managers and engineers to assess the level of complexity in their transportation projects. Companies can better anticipate potential difficulties, risks, and uncertainties in complex transportation projects and better plan for construction. As a result, scarce physical, capital, and human resources will be allocated wisely among transportation projects in their portfolio.

Country-specific findings were a limitation of this study. The project complexity parameters and their respective weights were for transportation projects in Vietnam. These parameters and their weights cannot be automatically used for other types of projects and/or in other countries without additional data collection. However, the proposed approach can be universally employed for evaluating the complexity of any project types in any regions.

References

Abednego, M.P., Ogunlana, S.O., 2006. Good project governance for proper risk allocation in public-private partnerships in Indonesia. Int. J. Proj. Manag. 24 (7), 622–634.

Baccarini, D., 1996. The concept of project complexity - A review. Int. J. Proj. Manag. 14 (4), 201–204.

Boender, C.G.E., de Graan, J.G., Lootsma, F.A., 1989. Multi-criteria decision analysis with fuzzy pairwise comparisons. Fuzzy Sets Syst. 29 (2), 133–143.

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., Verbraeck, A., 2011. Grasping project complexity in large engineering projects: The TOE. Int. J. Proj. Manag. 29 (6), 728–739.

Browning, T.R., 2014. Managing complex project process models with a process architecture framework. Int. J. Proj. Manag. 32 (2), 229–241.

Buckley, J.J., 1985. Fuzzy hierarchical analysis. Fuzzy Sets Syst. 17 (3), 233–247.

Chang, D.Y., 1996. Applications of the extent analysis method on Fuzzy AHP. Eur. J. Oper. Res. 95 (3), 649–655.

Cheng, C.H., 1997. Evaluating naval tactical missile systems by Fuzzy AHP based on the grade value of membership function. Eur. J. Oper. Res. 96 (2), 343–350.

Cicmil, S., Marshall, D., 2005. Insights into collaboration at the project level: complexity, social interaction and procurement mechanisms. Build. Res. Inf. 33 (6), 523–535.

Davies, E.M., 1973. An experimental investigation of resource allocation in multi-activity projects. Oper. Res. Q. 24 (4), 587–591.

Davis, E.W., 1975. Project network summary measures and constrained resource scheduling. IIE Trans. 7 (2), 132–142.

Deng, H., 1999. Multi-criteria analysis with fuzzy pairwise comparison. Int. J. Approx. Reason. 21 (3), 215–231.

Dewar, R., Hage, J., 1978. Size, technology, complexity, structural differentiation: Towards a theoretical synthesis. Adm. Sci. Q. 23 (1), 111–136.

El-Rayes, K., Moselhi, O., 2001. Impact of rainfall on the productivity of highway construction. J. Constr. Eng. Manag. 127 (2), 125–131.

Geraldi, G.G., Adlbrecht, G., 2007. On faith, fact, and interaction in projects. Proj. Manag. J. 38 (1), 32–43.

Ghosh, S., Jintanapakanont, J., 2004. Identifying and assessing the critical risk factors in an underground rail project in Thailand: a factor analysis approach. Int. J. Proj. Manag. 22 (8), 633–643.

Hass, K.B., 2009. Managing complex projects: A new model. Management Concepts, Vienna, VA, USA.

Jato-Espino, D., Castillo-Lopez, E., Rodriguez-Hernandez, J., Canteras-Jordana, J.C., 2014. A review of application of multi-criteria decision making methods. Autom. Constr. 45, 151–162.

Kaimann, R.A., 1974. Coefficient of network complexity. Manag. Sci. 21 (2), 172–177.

Kaming, P.F., Olomolaiye, P.O., Holt, G.D., Harris, F.C., 1997. Factors influencing construction time and cost overruns on high-rise projects in Indonesia. Constr. Manag. Econ. 15 (1), 83–94.

Klir, G.J., 1985. Complexity: Some general observations. Syst. Res. 2 (2), 131–140.

Le-Hoai, L., Lee, Y.D., Lee, J.Y., 2008. Delay and cost overruns in Vietnam large construction projects: A comparison with other selected countries. KSCE J. Civ. Eng. 12 (6), 367–377.

Liou, T.S., Wang, M.J.J., 1992. Ranking fuzzy numbers with integral value. Fuzzy Sets Syst. 50 (3), 247–255.

Meeampol, S., Ogunlana, S.O., 2006. Factors affecting cost and time performance on highway construction projects: evidence from Thailand. J. Financ. Manag. Prop. Constr. 11 (1), 3–20.

Meixner, O., 2009. Fuzzy AHP group decision analysis and its application for the evaluation of energy sources. Proceedings of the 10th International Symposium on the Analytic Hierarchy/Network Process, Pittsburgh, PA, USA.

Nassar, K.M., Hegab, M.Y., 2006. Developing a complexity measure for schedules. J. Constr. Eng. Manag. 132 (6), 554–561.

Nguyen, L.D., Ogunlana, S., Quang, T., Lam, K.C., 2004. Large construction projects in developing countries: A case study from Vietnam. Int. J. Proj. Manag. 22 (7), 553–561.

Ogunlana, S.O., Promkuntong, K., Jearkjirm, V., 1996. Construction delays in a fast-growing economy: comparing Thailand with other economies. Int. J. Proj. Manag. 14 (1), 37–45.

PMI, 2013. PMI's Pulse of the Profession In-Depth Report: Navigating Complexity. Project Management Institute, Newtown Square, PA.

PMI, 2014. Navigating Complexity: A Practice Guide. Project Management Institute, Newtown Square, PA.

Qureshi, S.M., Kang, C., 2015. Analysing the organizational factors of project complexity using structural equation modeling. Int. J. Proj. Manag. 33 (1), 165–176.

Saaty, T.L., 1980. The Analytic Hierarchy Process. McGraw-Hill, New York, NY, USA.

Saaty, T.L., 2005. Theory and Applications of the Analytical Network Process: Decision-Making with Benefits, Opportunities, Costs, and Risk. RWS Publications, Pittsburgh, PA, USA.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. Int. J. Serv. Sci. 1 (1), 83–98.

Saaty, T.L., Kearns, K.P., 1985. Analytical Planning – The Organizations of Systems. Pergamon Press, Oxford, UK.

Sambasivan, M., Soon, Y.W., 2007. Causes and effects of delays in Malaysian construction industry. Int. J. Proj. Manag. 25 (5), 517–526.

Satmetrix, 2003. Measuring satisfaction on a 0–10 scale, White paper. Satmetrix Systems, New York, NY, USA.

Sinha, S., Thomson, A.I., Kumar, B., 2001. A complexity index for the design process. WDK Publications, pp. 157–163.

Tatikonda, M.V., 1999. An empirical study of platform and derivative product development projects. J. Innov. Manag. 16 (1), 3–26.

Temperley, H.N.V., 1982. Graph Theory and Applications. John Wiley & Sons, Somerset, NJ, USA.

Tesfamariam, S., Sadiq, R., 2006. Risk-based environmental decision-making using fuzzy analytic hierarchy process (F-AHP). Stoch. Env. Res. Risk A. 21 (1), 35–50.

Thomas, J., Mengel, T., 2008. Preparing project managers to deal with complexity - Advanced project management education. Int. J. Proj. Manag. 26 (3), 304–315.

Toor, S., Ogunlana, S.O., 2008. Problems causing delays in major construction projects in Thailand. Constr. Manag. Econ. 26 (4), 395–408.

Vidal, L.A., Marle, F., 2008. Understanding project complexity: Implications on project management. Kybernetes 37 (8), 1094–1110.

Vidal, L.A., Marle, F., Bocquet, J.C., 2011a. Measuring project complexity using the Analytic Hierarchy Process. Int. J. Proj. Manag. 29 (6), 718–727.

Vidal, L.A., Marle, F., Bocquet, J.C., 2011b. Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects. Expert Syst. Appl. 38 (5), 5388–5405.

Wang, Y.-M., Chin, K.-S., 2011. Fuzzy analytic hierarchy process: A logarithmic fuzzy preference programing methodology. Int. J. Approx. Reason. 52 (4), 541–553.

Williams, T.M., 1999. The need for new paradigms for complex projects. Int. J. Proj. Manag. 17 (5), 269–273.

Xia, B., Chan, A.P.C., 2012. Measuring complexity for building projects: a Delphi study. Eng. Constr. Archit. Manag. 19 (1), 7–24.

Xia, W., Lee, G., 2005. Complexity of information systems development projects: Conceptualization and measurement development. J. Manag. Inf. Syst. 22 (1), 45–83.