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INTEGRAL METHODS OF FUZZY AHP AND DSM FOR EVALUATION IN PARTITIONING DESIGN TEAMS

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ABSTRACT: Many construction activities are related because they share the information of working methods and resources. Generally, the design information for coupled activities needs to be constantly collaborated in the different teams. To achieve the improvement in team collaboration, it is necessary to identify the relative coupled activities in the design teams. The activity and work partitioning arrangements are also required to accommodate the appropriate team members. This paper presents an integral method to be an evaluation in improving the collaboration for teams partitioning. A model, Team Partitioning Method (TPM) was developed to clarify the relationships between activities in a team. The results show the applicability of TPM model in team partitioning for design collaboration.

Keywords: Fuzzy integral; Fuzzy AHP; Design structure matrix; Partitioning; Design collaboration

1. INTRODUCTION

Efficiency can be improved if a design team is incorporated into the collaboration concerning schedules, working methods and resources. Studies have proven that improved collaboration can lead to significant savings in both cost and time for completing projects. The collaboration of design can achieve a reduction of the design life cycle, including [1] [2]. Ballard [3] proposed a method for reducing cycle time within the context of production. To reduce cycle time, it is necessary to break sequential processing from fragmented contractors. The potential for efficiency gains in the design processes is promising, but there is a need to reduce the wastes related to the flows, such as waiting for information, transformation of information and inspection [4]. In addition, the designer can participate directly in resolving design issues during construction. Improved design coordination can minimize project uncertainty by decreasing disruption and reducing waste in the construction processes. Some different design approaches were surveyed to reflect the contractual relationships in projects [5]. The design approaches showed that employees can become more involved with the project and utilize their abilities. Therefore, the lack of proper coordination among design disciplines is one of main barriers to reduce the amount of time for projects [6].

To ensure project success, it is important to choose suitable organizations to assistant their design abilities. The decisions of a design team may be determined or inappropriately influenced by unsuitable members. This is more likely to occur when the inappropriate members are on the same design team. When project participants display ineffective communication, this has been proven to affect the working ability to meet the owner's requirements and expectations of finishing the projects on time [7] [8]. In other words, well-defined team member roles and relationships are the key to a successful design. In addition, each design participant has a different obligation in the team. For a project to succeed, the engineering designers need to establish a direct relationship and line of communication with each other. The interface for engineering designers can become more open and promote a cooperative exchange of ideas to produce an advantageous project. It provides an opportunity for engineering designers to incorporate alternative technical concepts at the design phases to more efficiently deliver the project.

Design conflicts that result from interfering multi-disciplinary management systems are a preventable source of delay in engineering projects. Design coordination is the basis for reducing uncertainty in the various phases of a project. Due to the fact that most engineering projects are large and multidisciplinary, the possible interactions among the various participating departments need to be determined. Most engineering projects have created boundaries from these interactions during the design phase. Many research projects have revealed that this boundary has led to poor coordination in engineering projects, resulting in projects exceeding budgets and schedule datelines. Design activities are usually procedural and repeatable, and involve interactions between design and construction development. The difficulties in engineering projects do not arise simply from their technological complexity. Additional challenges in the design process result from the need to manage these interactions between the different disciplines.

2. MODEL BACKGROUND

Using various project management tools can facilitate different cases in the planning and management of design work. A knowledge tool was developed to assist engineers in determining sequential interactions and indicating these interactions in the format of Design Structure Matrix (DSM). There are some significant advantages to use DSM representation of the design process. Many researchers have adopted DSM representation to control tasks in projects. For example, it overcomes the problems caused by the size and visual complexity of all graph-based techniques through its compactness. DSM is a brief representation of complex processes providing a system view and clear rendering of potential iteration in process [9]. A successful multidisciplinary team must consist of representatives from all the activities that need to be considered to deal with the same information cycle. A study in the effective design tool DePlan was developed to offer a combined planning, scheduling and control methodology for integrated design management [10]. This tool can easily determine the activities required to meet the design criteria, the relationship between the activities and optimal sequencing. It showed that the DePlan tool facilitates an integrated approach in managing the design process. Some researchers have described the use of DSM to model and analyze a build process [11] [12]. Their research produced a tool to assist in the planning and management of complex, multi-disciplinary building design problems. The matrix in their research indicated groups of tasks that are interdependent and require careful coordination. It provided a structured means of scheduling a design process based on the flow of information through the project. Browning [13] reviewed two types of DSM and four DSM applications in system decomposition and integration problems. The activity-based DSM showed many advantages in his study. It provided process visibility and highlighted feedbacks in the potential iterations.

Smith and Eppinger [14] suggested that teams could consider strategies for reducing the number of iterations such as minimizing the team size. To minimize the interaction across the sub-groups, it needs to ensure the most important dependencies are in the same sub-group. This allows a core set of individuals to work more efficiently. Thus, the emphasis of this paper is placed on the problem of multidisciplinary organization to enhance the collaboration of designers in the groupings. To improve the efficiency and minimize the iterative communication, designers need to ensure that the most important dependent activities are in the same subgroup. In order to organize a cooperative team and direct its efforts, this paper proposes an integral method to be an evaluation in improving the collaboration for teams partitioning. A model, Team Partitioning Method (TPM) was developed to clarify the relationships between activities in groups. This study employs the Fuzzy Analytic Hierarchy Process (FAHP) and DSM to evaluate the coupling relationships on activities. It is helpful to solve sequential interactions to reduce the iterative design for all coupled activities through a variety of methods.

3. METHODS

Design iteration involves modification or improvement to previously worked activities. DSM representation can outline the development of design iteration by using basic configuration relationships. For example, there are three basic configuration relationships for system elements *A* and *B*. They are dependent (serial), independent (parallel) and interdependent (coupled). For dependent configuration, one element influences the behavior or decision of another element is a single directional fashion. That is, the design parameters of system element *B* are selected based on the design parameters of system element *A*. Element *A* has to be performed first before element *B* can start. For independent configuration, the system elements do not interact with each other. Understanding the behavior of the individual elements allows us to completely understand the behavior of the system. If the system was a design project, then system elements would be project activities to be performed. As such, activity *B* is said to be independent of activity *A* and no information exchange is required between the two activities. Finally, in the interdependent system, activity *A* influences activity *B* and activity *B* influences activity *A*. This would occur if activity *A* could not be determined (with certainty) without first knowing activity *B* and activity *B* could not be determined without knowing activity *A*. In general, the determination process requires decision makers to consider multiple, conflicting definitions in the use of uncertainty, incomplete or non-quantitative information.

3.1 Fuzzy Set Theory

Fuzzy set theory is a mathematical theory designed to model the vagueness or imprecision of human cognitive processes that pioneered by Zadeh [15]. The fuzzy set theory provides a rigorous, flexible approach to the problem of defining and evaluating the importance of relationship [16]. Since the fuzziness is not quantitatively measurable by nature, fuzzy logic can provide a way to systematically formulate a base for quantifying vagueness and uncertainty information. This is basically a theory of classes with ambiguous boundaries. It is a method which classical mathematical theories can be fuzzified. A fuzzification function is then established for the variables to express the associated measurement uncertainty. The purpose of fuzzy theory is to interpret the measurement of variables by replacing the crisp set with a fuzzy set. Application of fuzzy set theory can be found in many different sciences such as natural, life and social sciences, engineering, computer science, systems science and also in management and decision making [17]. In multi-criteria decision analyses, the fuzzy set theory can become the common method in dealing with uncertainty.

The main reason for the popularity of the fuzzy set approach is the sensitive analysis.

Fuzzy sets can have a variety of shapes. Generally, a triangle or a trapezoid can often provide an adequate representation of the expert knowledge and at the same time significantly simplifies the process of computation. Assume Â is a triangular fuzzy number defined as Â = (*a*, *b*, *c*), where *a*, *b*, and *c* are the lower bound, modal and the upper bound values (see Figure 1). According to the definition in [17], the fuzzy set must possess at least three properties: (1) Set A must be a normal fuzzy set; (2) $^{\alpha}A$ must be a closed interval for every $\alpha \in (0,1]$; (3) the support of set A, ^{0+}A must be bounded. Hence, the membership function $\mu_{\hat{A}}(x)$ can be defined as Equation (1):

$$\mu_{\hat{A}}(x) = \begin{cases} 0 & , x < a \\ \dfrac{x - a}{b - a} & , a \le x \le b \\ \dfrac{c - x}{c - b} & , b \le x \le c \\ 0 & , x > c \end{cases} \qquad (1)$$

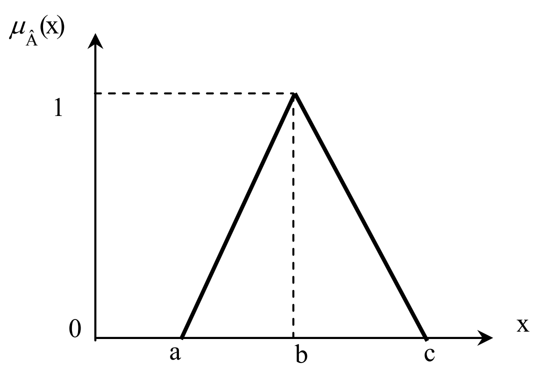

Figure 1. The Membership Function of the Triangular Fuzzy Number $\mu_{\hat{A}}(x)$

Fuzzy arithmetic is based on each fuzzy set and its α-cut properties of fuzzy numbers. For two fuzzy number $\hat{A}_1 = (a_1, b_1, c_1)$ and $\hat{A}_2 = (a_2, b_2, c_2)$, the four arithmetic operations on closed intervals are defined as follows:

$$\hat{A}_1 \oplus \hat{A}_2 = (a_1, b_1, c_1) \oplus (a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \qquad (2)$$

$$\hat{A}_1 \otimes \hat{A}_2 = (a_1, b_1, c_1) \otimes (a_2, b_2, c_2) = (a_1 a_2, b_1 b_2, c_1 c_2) \qquad (3)$$

$$\hat{A}_1 \varnothing \hat{A}_2 = (a_1, b_1, c_1) \varnothing (a_2, b_2, c_2) = (a_1 / c_2, b_1 / b_2, c_1 / a_2) \qquad (4)$$

$$(\hat{A}_1)^{-1} = (a_1, b_1, c_1)^{-1} = (1/c_1, 1/b_1, 1/a_1) \qquad (5)$$

where ⊕ , ⊗ and ∅ denote fuzzy addition, multiplication and division.

3.2 Linguistic Variables

Linguistic variables are represented on an ordinal scale. Normally linguistic variables are not exactly measurable and may be categorized into any one of the linguistic variables. Hence linguistic variable can also be called fuzzy variable and modeled by fuzzy sets. A linguistic variable is defined by the name of the variable, the linguistic values and the membership functions of the linguistic values [17].

An idea of fuzzy set theory is that an element has a degree of membership in a fuzzy set [18]. The membership function represents the grade of membership of an element in a set. The membership values of an element vary between 0 and 1. Elements can belong to a set in a certain degree and elements can also belong to multiple set. Fuzzy set allows the partial membership of elements. Hence, the membership function can gradually map the variation of value of linguistic variables into different linguistic classes [19]. The level from the relative importance between interdependent activities can be considered as linguistic variables. Each of linguistic variables has its respective linguistic classes such as equally important, moderately more important, strongly more important, very strongly more important and extremely more important, as shown in Figure 2.

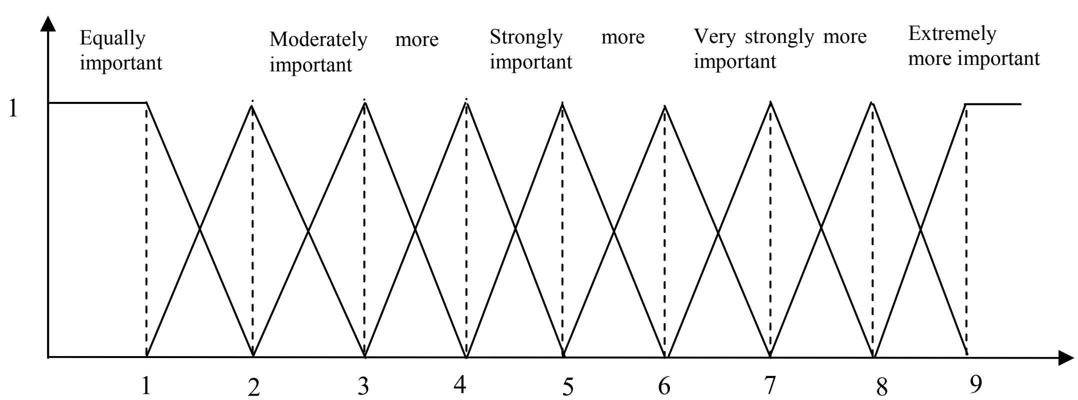

Figure 2. Possible Fuzzy Quantization of the Range [1, 9] by Triangular Fuzzy Numbers

3.3 Fuzzy AHP

Human knowledge is imprecise in nature. It is usually the case that the knowledge is neither totally certain nor totally consistent. For a problem of decision making, the result usually needs to be obtained through the rule reasoning, which involves a complex process [20]. The AHP technique was developed in solving the priorities and the criteria were used to judge the alternatives [21]. These priorities are derived based on pairwise comparison judgment. The criteria are usually measured on different scales when these criteria are quantitative and qualitative. However, the AHP technique is criticized for its inability to handle the uncertainty and imprecision associated with the mapping of the decision maker's perception to a crisp number [22]. Buckley [23] proposed the FAHP to assess the importance for evaluators in the different criterion. Most activities and their interactions can provide information about the relative degree of importance and frequency of interdependencies. It can overcome the inability of AHP and handle the imprecision in the pairwise comparison process. One study [24] proposed a fuzzy modification of AHP as an evaluation technique in negotiations over services. In their study, a fuzzy pairwise comparison judgment was used to transform the initial fuzzy prioritization problem into a non-linear program.

The FAHP is a multi-criteria decision making technique, which has been widely used to make the pairwise comparison judgments. It assists a flexible decision making process to handle the obscure linguistic scale throughout the hierarchy to arrive at overall priorities for the alternatives. In decision analysis, the FAHP is one of the most popular methods for ranking orders among a set of alternatives. In general, the FAHP can be utilized in the triangular fuzzy numbers to model the pairwise comparison in order to elicit weights of preference. It is also used to express the decision maker's assessments on alternatives with respect to each criterion. The practical applications were reported in the literature [25] [26] [27]. For example, the triangular fuzzy numbers can be constructed in the pairwise comparison process with n elements to express the assessments as follows:

$$\hat{A} = \begin{bmatrix} 1 & \hat{a}_{12} & \hat{a}_{13} & \cdots & \hat{a}_{1n} \\ \hat{a}_{21} & 1 & \cdots & \cdots & \hat{a}_{2n} \\ \hat{a}_{31} & \hat{a}_{32} & \ddots & & \\ \vdots & \vdots & & \ddots & \vdots \\ \hat{a}_{n1} & \hat{a}_{n2} & \cdots & \cdots & 1 \end{bmatrix} \quad (6)$$

The concept of fuzzy extent analysis is applied to solve the fuzzy reciprocal matrix for determining the criteria importance and alternative performance, such as

$$\hat{A} = \left[\hat{a}_{ij} \right] = \left[\frac{1}{\hat{a}_{ji}} \right] \quad (7)$$

where $\hat{a}_{ij}$ = the activity i is relative importance to the activity j

Many design activities involve couplings, especially for these couplings in various degrees of strength. The FAHP can be applied to measure the strength of coupled design activities to reduce the number of couplings the comparison through the pairwise comparison. The evaluators usually observe the weight with their own subjective evaluation. As a result, an exact weight for a specified criterion is difficult to obtain. This leads to the use of the fuzzy weights for criteria. Measurements are converted into appropriate fuzzy sets to express measurement uncertainties. Buckley [23] proposed to derive the fuzzy weights of criteria by using the geometric mean in calculating different values. He considered a fuzzy positive reciprocal matrix $\hat{A} = \left[\hat{a}_{ij} \right]$, extending the geometric mean technique to define the fuzzy geometric mean of each row $\hat{r}_i$ and fuzzy weight $\hat{w}_i$ corresponding to each criterion as follows

$$\begin{aligned} \hat{r}_i &= (\hat{a}_{i1} \otimes \hat{a}_{i2} \otimes \cdots\cdots \otimes \hat{a}_{in})^{1/n} \\ \hat{w}_i &= \hat{r}_i \otimes (\hat{r}_1 \oplus \hat{r}_2 \cdots\cdots \oplus \hat{r}_n)^{-1} \end{aligned} \quad (8)$$

The result of fuzzy decisions reached by each alternative is a fuzzy number. Consider the fuzzy prioritization; it is necessary to use the real ranking through the fuzzy numbers for comparison of the alternatives. The defuzzification process is to convert these output grades back to real world crisp output values. A number of defuzzification methods leading to distinct results were proposed in the literature [28] [29]. In the defuzzification procedure, the best nonfuzzy performance (BNP) value will be located. For example, The value of the triangular fuzzy number (l_i ,m_i, u_i) can be found by the following equation:

$$BNP_i = [(u_i - l_i) + (m_i - l_i)] / 3 + l_i \quad (9)$$

From the Equation (9), the BNP value in the ranking evaluation of each alternative can be obtained.

3.4 Integral FAHP and DSM

In this paper, the integration of the TPM model with the DSM and FAHP methods is described to evaluate the coupling relationships on activities. The DSM method can re-sequence activities to reduce iterations in the design process. Partitioning is the process of manipulating the DSM rows and columns so that the new DSM arrangement does not contain any feedback marks. Off-diagonal marks in a single row of the DSM can be drawn for all of the activities whose output information is required to perform the activity corresponding to that row. This mark is called a forward information link. Similarly, reading down a specific column reveals which activity receives information from the activity corresponding to that column. Those marks below the diagonal represent the activity information transfer to later (downstream) activities are backward information links. This concept can identify the relative importance of the different tasks that have an impact when deciding the proper grouping arrangement. It can also produce the pairwise comparison judgments throughout the hierarchy to arrive at overall priorities for the alternative groupings. For the forward and backward information in the DSM, the TPM model represents the integrated forward and backward information in design process. It usually involves the consistent analysis of the activities for the relative coupling importance. In addition, consistent analysis is also related to decision making in the design process.

For grouping in collaboration, FAHP is carried out in two steps. The design activity is the first step and a hierarchy is established. Then comes the evaluating phase, which is comprised of the pairwise comparisons. The design of the hierarchy requires an evaluator's experience and knowledge of the problem area. An evaluation results in the determination of a ratio scale of relative values. The second step is the fuzzy evaluation, in which each grouping (decision) is compared to all other groupings (decisions). This is done in a fuzzy pairwise matrix format.

In the past, clustering techniques have been widely applied in a variety of scientific areas such as pattern recognition, information retrieval, microbiology analysis, and so forth. Clustering analysis is a fundamental but important tool in statistical data analysis. One of the most commonly used clustering algorithms, the K-means clustering technique, aims at assigning each pattern of a given data set to the cluster having the nearest centroid. The idea behind this is to identify a group of patterns from within the entire data set, which are sufficiently 'close' or 'similar' to each other. The K-means simply signifies the number of clusters into which data are to be partitioned. It consists of an algorithm to classify or to group objects based on attributes/features into K number of groups. K is a positive integer number. The grouping is done by minimizing the sum of squares of distances between data and the corresponding cluster centroid. In activity grouping process, the purpose of K-means clustering is to classify the data, which come from the defuzzification procedure. The clustering analysis is used to measure differences and association between variables. The measure of differences is used to analyze the differences in the current collaborative practices among the project participants in different departments. The measure of association is used to analyze the influence, if any, of the current collaborative practices on the project performances.

4. CASE STUDY

The case study is from the Taiwan High Speed Rail (THSR) project, which is used to show the implementation of collaborative improvement in design. The C260 contractor has established dedicated multi-disciplinary work teams with the task of implementing the wide and diverse range of contracts that make up the THSR project [30]. This study was investigated by conducting a viaduct construction part to gain information on the participants' understanding of communication by assessing the current collaborative practices and their impact on THSR project.

4.1 Building A Hierarchical Design

Design output occurs as a result of each design development stage for each design unit. Validation of the design is done through the process of examination, auditing and spot-checking of records and reports in relation to the design of permanent works. Design development of interface relevant elements is based on the information provided. With regard to interfaces such progress of detailing is as follows:

Design Unit: A distinct portion of the works, the design of which is performed as a contiguous, integrated unit.

Design Level: A sequence of levels defined by the output information required for a particular design development stage.

Design for the works occurs in development stages. For each development stage, levels of design are defined, which provide the details that are to be included in the design output at each respective stage of design [30]. The designer will certify that the design for the particular design unit is complete, checked and ready to be released for construction. Conflicts can be resolved to reduce the dependency on detailed information for particular elements as much as possible for each respective design development stage. All design and drawings for the works are packaged into separate design unit. In order to facilitate design reviews and the start of construction of portions before all design within a design unit has been completed, the levels of completion of the design information for each stage of development are defined. Each design unit will comprise similar and coherent significant parts of the work, which can be checked and reviewed as a self-contained package. Two or more design units may be used for production of design and drawings for large numbers of similar structures. The timing of information delivered during the design development between early start and late finish for each design unit is compatible with the information required for the respective development stage. The designer will confirm such compatibility for each design unit and construction activity taking time constraints into consideration.

The relationship of design units for a simple sketch of a viaduct is shown in Figure 3. The design of the viaduct is subdivided into 'Definitive Design' (DD), 'Intermediate Design' (ID), 'Final Design' (FD), 'Construction Design' (CD), and 'As-Constructed Design' (AD), five stages in all. The viaduct can be built without completion of design across all units. After the completion of all elements in the design drawings, construction drawing can start. The design unit is then delivered to construction in sequence. At the different level, these activities are decomposed into various attributes that may affect the partitioning of design teams. The designers manage the process based on release of prerequisite information from the earlier design stage. Thus, design and construction are integrated into a work package to meet the requirement of THSR project.

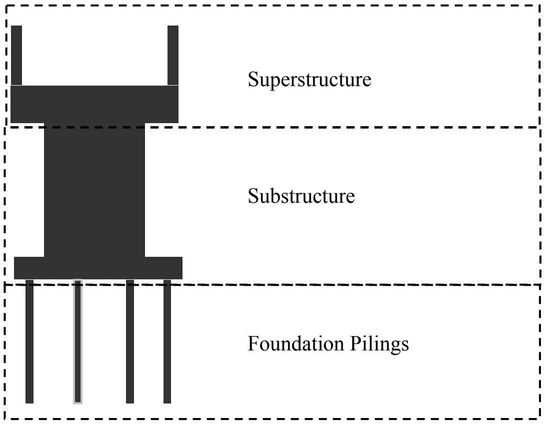

Figure 3. The Design Units for Viaduct Sketch

The characteristics of different design levels have a variety of influences on the process of the collaborative analysis to reduce/increase activities from the viaduct design. The various types of activities require different information flow and management priorities. It is better to assign a notation to each of the activities to facilitate calculation of appropriate work sequence. With respect to these activities, the notations in hierarchical structure can show the level of design. For example, the activity (Setting-out of all major units) of design level is notated as A_1, and the activity (details affecting appearance of the structures) as A_6. Thus, these activities are notated from A_1 to A_{20} for viaduct design as follows:

A_1: Setting-out of all major units;
A_2: Location and nature of all relevant joints and connections;
A_3: Summary of output of track-structure interaction analysis;
A_4: Design showing installation method for foundation piles;
A_5: Erection and construction methods;
A_6: Details affecting appearance of the structures;
A_7: Structural global analyses;
A_8: Design drawings for piers and foundations;
A_9: Detail design of piers and foundations for simple structures;
A_{10}: Rigorous track-structure interaction analysis;
A_{11}: Settlements and displacements;
A_{12}: Stress analyses;
A_{13}: Complete section drawings;
A_{14}: Complete works specifications;
A_{15}: Detailed design and design drawings of finishes;
A_{16}: Complete standard drawings;
A_{17}: Fixing details for attachments and finishes to be complete with reinforcement schedules;
A_{18}: Construction design and construction drawings comprise reinforcement concrete design and drawings;
A_{19}: Works specifications and design drawings for architectural and structural details;
A_{20}: Prepare as-built drawings showing all changes from the final design drawings;

4.2 Design Activities for DSM

Based on the THSR project participants' design experience, the relationships among activities of grouping in collaboration are analyzed. Table 1 shows DSM representations of these activities from the relationships. The sequencing done by the experienced engineers is based on the information contained in the activities. The "x" marks in DSM denote the dependency of the corresponding row activity on the column activity. Most activities take priority are too complex to accurately be predicted in the design condition. Analyzing these activities and their interactions can provide information about the relative potential degree of importance and frequency of interdependency. The goal in DSM is to re-sequence these activities and to reduce iterations in the design process. Partitioning is the process of manipulating the DSM rows and columns such that the new DSM arrangement does not contain any feedback marks. Thus, the objective of analysis changes from eliminating the feedback marks to move them as close as possible to the diagonal. In doing so, fewer design activities will be involved in the iteration cycle resulting in a faster design development process. There are several approaches used in DSM partitioning. The method of path searching is adopted in this study to identify iterations of collaboration.

The steps of path searching partition for viaduct design activities proceed as follows:

(a) Activities A_5 did not depend on information from any other activities as indicated by an empty row. A_5 was removed in the matrix from further consideration. The forwards loop FL = $\{A_5\}$ was in the process sequence.

(b) Again, activities A_1, A_8, A_4, A_9 and A_{14} did not depend on information from any other activities as indicated by an empty row. A_1, A_8, A_4, A_9 and A_{14} were removed in the matrix from further consideration. The forwards loop FL = $\{A_5, A_1, A_8, A_4, A_9, A_{14}\}$ was in the process sequence.

(c) Activity A_6 did not depend on information from any other activities as indicated by an empty column. A_6 was removed in the matrix from further consideration. The backwards loop BL = $\{A_6\}$ was in the process sequence. Again, activity A_{20} did not depend on information from any other activities as indicated by an empty column. A_{20} was removed in the matrix from further consideration.
The backwards loop BL = $\{A_{6\ ,} A_{20}\}$ was in the process sequence.

(d) Now, no activities have empty rows or columns. Only12 activities were interdependent in DSM, as shown in Table 2. A loop exists and can be traced starting with any of these activities. Therefore, 12 activities could be divided into two groups, i.e. $G_1 = \{A_2, A_3, A_7, A_{10}, A_{12}, A_{13}, A_{15}, A_{16}, A_{19}\}$ and $G_2=\{A_{11}, A_{17}, A_{18}\}$.

(e) From (d), the forwards loop becomes FL = $\{A_3, A_7, A_{12}, A_9, A_2, A_{13}, A_{15}, G_1, G_2\}$ or BL = $\{A_{6\ ,} A_{20}\}$.

Table 1 The Activities in DSM Representations

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}
A_1					x															
A_2	x		x	x			x		x			x								
A_3	x	x			x			x		x		x								
A_4	x				x			x												
A_5																				
A_6								x	x				x			x		x		
A_7	x	x							x							x			x	
A_8	x																			
A_9								x												
A_{10}	x	x	x						x			x							x	
A_{11}								x	x			x						x	x	
A_{12}								x	x				x			x				
A_{13}		x						x		x		x								
A_{14}					x															
A_{15}							x			x			x							
A_{16}							x	x	x				x		x					
A_{17}											x		x		x	x				
A_{18}								x								x	x			
A_{19}										x			x	x	x	x				
A_{20}									x							x				

Table 2. Interdependent Activities in DSM

	A_2	A_3	A_7	A_{10}	A_{11}	A_{12}	A_{13}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}
A_2		x	x			x						
A_3	x			x		x						
A_7	x								x			x
A_{10}	x	x				x						x
A_{11}						x					x	x
A_{12}							x		x			
A_{13}	x			x		x						
A_{15}			x	x			x					
A_{16}			x				x	x				
A_{17}					x		x	x	x			
A_{18}									x	x		
A_{19}				x			x	x	x			

The final partitioned matrix is {A_5, A_1, A_8, A_4, A_9, A_{14}, G_1, G_2, A_6, A_{20}}. Activities {A_5, A_{14}} are independent. Activities {A_1, A_8, A_4, A_9} are dependent. It can be the responsibility of one engineer or of a multidisciplinary team to manage those activities in a sequence. Activities {A_2, A_3, A_7, A_{10}, A_{12}, A_{13}, A_{15}, A_{16}, A_{19}} and {A_{11}, A_{17}, A_{18}} are interdependent. It needs a multidisciplinary team to control these work groupings.

From DSM partitioning of viaduct design activities, the number of tasks for G_1 and G_2 grouping are evaluated to set up a multidisciplinary team. Constraints always exist in a multidisciplinary team when project participants are arranged. The breaking down of these complex activities is an important concern in this collaboration. Before decomposition, the scale of direction (forward information link) needs to be evaluated from interdependent activities in grouping. The activities collaboration cannot easily be distinguished from the binary value in DSM. For the activities relationship evaluation, FAHP is employed to model and generate a relative weight/rank for comparing coupled design tasks. In pairwise comparisons, the application of a reciprocal rule can derive the number of comparisons for the competing elements. To define a scale relation that exists between two different activities, it is possible to define a fuzzy relation among the activities. Designers usually rely on common sense when they judge these relationships of activities. Sometimes, vague and ambiguous scales are also used. All the activities were investigated to scale their relations from 1 (equally important), 3 (moderately more important), 5 (strongly more important), 7 (very strongly more important) to 9 (extremely more important). The alternates are scale 2, 4, 6 and 8. Collaborative scoring is a technique for assigning conditions or scores, which contribute to the collaborative profile. The investigation focuses on the understanding of the various tasks of communication improvement and its impact on project performance. The relationships between the activities are scaled and the results are then compared pairwise to evaluate consistency in the importance of forward and backward information links for each activity. To ensure the correct order in priority of importance for each individual collaborative group, a separated collaborative scale is calculated for individual collaboration. From individual collaborative scales, a weighted average is applied to each collaborative group. The results are finally entered into a fuzzy pairwise comparison matrix then solved for their relative weights. The weights are used for averaging the individual activities for overall project objectives. According to the important degree of information forward input, there will be 9 fuzzy pairwise comparison matrices produced to do evaluation for activities {A_2, A_3, A_7, A_{10}, A_{12}, A_{13}, A_{15}, A_{16}, A_{19}}.

5. DISCUSSION

The evaluation process is based on the proposed FAHP method to partition the coupled activities. The first step in applying the FAHP is to construct a hierarchy of design level. It was supposed that the default number of members of a multidisciplinary team is six people and each member could manage only one activity at a given time. Clearly, the requirements for the {A_2, A_3, A_7, A_{10}, A_{12}, A_{13}, A_{15}, A_{16}, A_{19}} multidisciplinary team exceeded this limit. In the next step, the decision-making process, the important relationships of all activities are to be derived from fuzzy pairwise comparison matrices. The fuzziness assessment using FAHP method is the fuzzy pairwise comparison matrices that were used in the linguistic scale. The fuzzy number is represented by a triangular membership function, which have 3 values (left, middle, right). In the current research, the value 1 to 9 was used in fuzzy numbers; it means the experts have the level about the important relationships chosen. Conversion from crisp pairwise comparison matrices to fuzzy pairwise comparison matrices can be evaluated. For example, the elements of the fuzzy pairwise comparison matrices do not have the same scale as follows:

$\hat{1}$: (1, 1, 2) $\quad \hat{1/1}$: (1/2, 1/1, 1/1)

$\hat{3}$: (2, 3, 4) $\quad \hat{1/3}$: (1/4, 1/3, 1/2)

$\hat{5}$: (4, 5, 6) $\quad \hat{1/5}$: (1/6, 1/5, 1/4)

$\hat{7}$: (6, 7, 8) $\quad \hat{1/7}$: (1/8, 1/7, 1/6)

$\hat{9}$: (8, 9, 9) $\quad \hat{1/9}$: (1/9, 1/9, 1/8)

To deal with the imprecise values in the pairwise comparison process, it has been improved in FAHP. Instead of single crisp value, the FAHP is used in a range of value to incorporate the decision uncertainty. The elements can be compared if they have the uniform linguistic scale. To perform assessment in FAHP, the fuzzy pairwise comparison matrices were used the conversion in the fuzzy geometric mean. It is constructed as follows:

$$\begin{array}{c} \\ A_3 \\ A_7 \\ A_{12} \end{array} \begin{array}{c} \begin{array}{ccc} A_3 & A_7 & A_{12} \end{array} \\ \begin{bmatrix} 1 & \hat{3} & \hat{5} \\ \hat{\frac{1}{3}} & 1 & \hat{3} \\ \hat{\frac{1}{5}} & \hat{\frac{1}{3}} & 1 \end{bmatrix} \end{array}$$

$$= \begin{array}{c} \\ A_3 \\ A_7 \\ A_{12} \end{array} \begin{array}{c} \begin{array}{ccc} A_3 & A_7 & A_{12} \end{array} \\ \begin{bmatrix} 1 & (2,3,4) & (4,5,6) \\ (1/4,1/3,1/2) & 1 & (2,3,4) \\ (1/6,1/5,1/4) & (1/4,1/3,1/2) & 1 \end{bmatrix} \end{array}$$

To use Equation (8) for row A_3 to determine:
The fuzzy geometric mean of each row

$$\hat{r}_1 = ((1\times2\times4)^{1/3}, (1\times3\times5)^{1/3}, (1\times4\times5)^{1/3})$$
$$= (2.0, 2.466, 2.884)$$

Similarly,

$$\hat{r}_2 = (0.794, 1.0, 1.260)$$

$$\hat{r}_3 = (0.347, 0.405, 0.500)$$

After obtaining the fuzzy geometric mean of each row, the fuzzy weights performance can be analyzed in the following procedure:

The fuzzy weight $\hat{w}_1$ = (2.0, 2.466, 2.884) ⊗ (1 / (2.884 + 1.260 + 0.500), 1 / (2.466 + 1.0 + 0.405), (1 / (2.0 + 0.794 + 0.347)) = (0.431, 0.637. 0.919)

Similarly

$$\hat{w}_2 = (0.171, 0.258, 0.401)$$

$$\hat{w}_3 = (0.075, 0.105, 0.159)$$

Thus, the *BNP* value from Equation (9) can be obtained as follows:

BNP_1 = ((0.919-0.431)+(0.637-0.431))/3 + 0.431 =0.662
BNP_2 = 0.277
BNP_3 = 0.113

For the proportion of important relationships in comparison, it can be obtained from the following process:

$BNP_1 / (BNP_1+BNP_2+BNP_3) = 0.629$
$BNP_2 / (BNP_1+BNP_2+BNP_3) = 0.263$
$BNP_3 / (BNP_1+BNP_2+BNP_3) = 0.107$

All row and column data was calculated together to get information on forward input matrix (F) and backward output matrix (B). This evaluation is applied for all fuzzy elements in the actual performance and results are shown in the following:

$F =$

	A_2	A_3	A_7	A_{10}	A_{12}	A_{13}	A_{15}	A_{16}	A_{19}
A_2	1	0.629	0.263		0.107				
A_3	0.512	1		0.345	0.143				
A_7	0.643		1					0.285	0.072
A_{10}	0.159	0.500		1	0.295				
A_{12}					1	0.742		0.258	0.046
A_{13}	0.652			0.171	0.177	1			
A_{15}			0.662	0.064		0.274	1		
A_{16}			0.646			0.298	0.056	1	
A_{19}				0.155		0.642	0.155	0.048	1

$B =$

	A_2	A_3	A_7	A_{10}	A_{12}	A_{13}	A_{15}	A_{16}	A_{19}
A_2	1	0.742	0.629		0.517				
A_3	0.500	1		0.562	0.229				
A_7	0.295		1					0.503	0.258
A_{10}	0.160	0.258		1	0.203				
A_{12}					1	0.453		0.431	0.742
A_{13}	0.045			0.243	0.051	1			
A_{15}			0.263	0.138		0.328	1		
A_{16}			0.108			0.128	0.742	1	
A_{19}				0.057		0.091	0.258	0.066	1

The numerical matrix contains the input and output information from the tasks with couplings. It was necessary to measure the strength of activity coupled by using the geometric mean method. From calculating the elements in the information input matrix and the output matrix, the combined numerical matrix (C) was obtained. The relationships of importance are indicated by the crisp element values. Element with larger values have higher importance. A higher value means the activity has more contribution in partitioning groups than the other activities. The element value not only calculates the direct impact of an activity through its direct connection to other activities but also its indirect connection to other activities. The member constraint always exists in a multidisciplinary team when project participants are arranged. The breaking down of these {A_2, A_3, A_7, A_{10}, A_{12}, A_{13}, A_{15}, A_{16}, A_{19}} activities was an important concern in this collaboration.

Before decomposition, the scale of information forward input and backward output link needed to be evaluated fr om interdependent activities in the {A_2, A_3, A_7, A_{10}, A_{12}, A_{13}, A_{15}, A_{16}, A_{19}} grouping. After this process, the K-means clustering algorithm was chosen to determine an a dequate design activity for the new subgroups. The coupl ed activities that depended tightly on other activities need ed to be broken down further. In order to get a better appr eciation of the performance of the TPM model, a compari son of grouping activities produced by other techniques w as necessary.

$C =$

	A_2	A_3	A_7	A_{10}	A_{12}	A_{13}	A_{15}	A_{16}	A_{19}
A_2	1	0.683	0.407		0.235				
A_3	0.505	1		0.440	0.181				
A_7	0.436		1					0.379	0.136
A_{10}	0.159	0.359		1	0.245				
A_{12}					1	0.580		0.333	0.185
A_{13}	0.171			0.204	0.095	1			
A_{15}			0.417	0.094		0.300	1		
A_{16}			0.264			0.195	0.204	1	
A_{19}				0.094		0.242	0.200	0.056	1

The TPM model was useful in identifying where iteration was necessary, and could predict slow or rapid convergence of iteration within a project. For the process, the K means clustering functions in such a way that strongly coupled activities are clustered together based on member constraints. As seen from Table 3, the measure indicates the activities {A_{10}, A_{12}, A_{13}} and activities {A_2, A_3, A_7, A_{15}, A_{16}, A_{19}} in two clusters to be the optimal partition. This grouping result demonstrates that the TPM model can also work well for this example of grouping with various coupled activities.

Table 3. The Clustering for Design Activities

Design Activities	Group No.
A_2	1
A_3	1
A_7	1
A_{10}	2
A_{12}	2
A_{13}	2
A_{15}	1
A_{16}	1
A_{19}	1

In addition, the model requires consideration of the interactive influences in the different design modes rather than a numerical judgment. The TPM model can be used if the transformation matrices are not known or can not be easily obtained. Using the TPM model method, the subgroups of determination for the coupled activities can be considered as a type of clustering problem. This has been repartitioned to ensure the most important dependencies are close as possible. Therefore, a nine-coupled-activity group can be decomposed into two subgroups, i.e. one is a three-coupled-activity subgroup and the other is six-coupled-activity subgroup. These two small work teams are more helpful than a large nine-member team. In addition, the members in these two subgroups can work concurrently. Thus, in a new repartitioned matrix based on the TPM model, the coupled activities are rearranged and the modified DSM for the viaduct design is finalized, as shown in Table 4.

Table 4. Modified DSM for Viaduct Design Activities

	A_5	A_1	A_8	A_4	A_9	A_{14}	A_2	A_3	A_7	A_{15}	A_{16}	A_{19}	A_{10}	A_{12}	A_{13}	A_{11}	A_{17}	A_{18}	A_6	A_{20}
A_5																				
A_1	x																			
A_8		x																		
A_4	x	x	x																	
A_9			x																	
A_{14}	x																			
A_2		x		x	x			x	x					x						
A_3	x	x	x				x						x	x						
A_7		x			x		x				x	x								
A_{15}									x				x		x					
A_{16}			x		x				x	x					x					
A_{19}						x				x	x		x		x					
A_{10}		x			x		x	x				x		x						
A_{12}			x		x						x				x					
A_{13}			x				x						x	x						
A_{11}			x		x							x		x				x		
A_{17}										x	x				x	x				
A_{18}			x								x						x			
A_6			x		x						x				x			x		
A_{20}					x						x									

6. CONCLUSIONS

Although it is generally believed that grouping is useful for facilitating the coordination of processes, it can also hinder the engagement of members in collaborative activities if the groupings are not properly arranged. This study is to explore how the implementation of techniques can lead to better grouping in organizational communication and collaboration for the design process. The objective of the research is to explore the application of the DSM method as well as the FAHP in the assessment of partitioning teams to the coupled activities in the design process. Regrouping coupled activities that depend strongly on each other can create less inter-organizational interfaces. Each design level in the design process consists of a series of identifiable activities that can be traced back to the original design requirement. However, due to the large number of members on a team, the efficiency of communication and collaboration will definitely be decreased. The proposed TPM model has been developed to deal with the problem of grouping coupled activities: finding subgroups able to increase the efficiency of communication and collaboration. During the design process, a number of design characteristics and a sequence of transformations are described by the DSM technique. The transformations are involved in the processing of task information as design moves from different levels. Efficient strategies enable members in organizations to achieve collaboration that can improve their decision-making processes and in turn enhance their efficiency. The TPM model has the benefit in handling linguistic variables and uncertainty that occurs in experts' judgment when they derive the pairwise comparison matrix. It explores the relative importance of relationships at the different levels that represent the role of each activity in partitioning teams. Grouping design teams must be flexible enough to avoid obstructing an individual approach to design. Specifically, the constraints in grouping, in which achieve better organizational communication and collaboration in arrangement must be considered. This study focuses on addressing the problem of "how to group" by developing the influence of an FAHP strategy with K-means clustering on organizational effectiveness through DSM. In this paper, the TPM model for the grouping of collaborative teams under constraints is presented that allows for the creation of organizational communication on a design project. Clearly, the new, integrated method will benefit design engineers and managers by facilitating more precise control of their work teams through the more effective sequencing of the various design activities.

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