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A new approach for project scheduling using fuzzy dependency structure matrix

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Abstract

As an alternative solution, the Dependency Structure Matrix (DSM) is a useful tool in project scheduling when approaching information dependency issues between activities. However, the current DSM approach faces the dilemma that the overlap of activities cannot be precisely estimated in the planning stage of a project, and the solution calls for a robust methodology for managing schedules within uncertain conditions of information dependency. The aim of our research is to propose an approach that utilizes fuzzy set theory to solve the problem within an uncertain environment. As an extension of traditional DSM-based scheduling, we describe the overlap and duration of activities as fuzzy numbers and put forth a systematic algorithm to calculate the time variables of activities and project duration thereof. An example is also provided to demonstrate the effectiveness of the algorithm.

Keywords: Project scheduling; DSM; Fuzzy set theory; Project management

1. Introduction

The technique traditionally used in project time management is the Critical Path Method (CPM) for the planning and control of complicated projects. However, traditional CPM, which is based on the descriptions of task flows using graphic symbols, is not suitable for sequence management, especially for modeling information flow (Eppinger, 2001; Eppinger et al., 1994; Yassine et al., 1999). Therefore, the Dependency Structure Matrix, or Design Structure Matrix (DSM), a new technique for the description of information flow, has been employed as a useful tool for coping with design issues of complex systems (Steward, 1981). Following this stream, a separate branch of research based on DSM has been conducted to address the problem of information flow for project scheduling (Carrascosa et al., 1998; Chen et al., 2003; Maheswari and Varghese, 2005). In DSM-based scheduling, it is necessary to capture the "communication time" needed for collecting information before and during the execution of activities (Maheswari and Varghese, 2005: 224). This communication time includes time for meetings, processing emails, waiting time for decisions, and activities conducted to collect information. In addition, the overlap of activities is important and should be addressed in order to estimate correctly and meet the compressed project duration.

However, the estimation of overlapping project duration along with communication time is, to some degree, vague and uncertain in real applications. Maheswari and Varghese (2005) classified the overlapping of activities into two types: natural overlapping and forced overlapping. They argued that natural overlapping, which involves minimum risk, could be calculated by matching or merging the time at which information exchange between activities occurs. This time is usually described with a ratio or "time factor." By defining the ratio as a certain number, Maheswari and Varghese proposed an approach to model a project schedule based on DSM.

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In fact, the definition of a ratio is a matter of fuzziness that is far beyond simplicity within a complex project condition. “Fuzzy” is not a new term in research related to project scheduling; on the contrary, vagueness and uncertainty have been topics for current discussion regarding project scheduling (Chen and Hsueh, 2008; Chen and Huang, 2007; Ke and Liu, 2010; Li et al., 2006; Liberatore, 2008; Zareei et al., 2011). However, these research endeavors are based on merely the traditional fundamental approaches of CPM and PERT, which creates a need for our research to study the fuzzy attributes of overlapping between activities in the process of project scheduling on the base of the DSM approach.

In this paper, we intend to propose an approach to capture the problems caused by fuzziness in the process of defining the ratio of information exchange among activities in DSM. The aims of our research are: (1) Identify the essence of information dependencies between activities in project scheduling; (2) Design an algorithm of DSM-based project scheduling within fuzzy environment; (3) Test the effectiveness of the proposed new approach.

In the next section, we analyze the advantage of DSM over traditional methods such as CPM and PERT as well as the difficulties of the DSM approach in dealing with the fuzziness of project environment for practical application. In the third section, we present a new algorithm to address the problems of fuzziness in DSM-based project scheduling. An example is then provided to demonstrate the effectiveness of the algorithm in the fourth section. In the fifth section, we engage in further discussion on how to use this novel approach. Conclusions and further research directions are offered in the last section.

2. CPM and PERT versus DSM

The traditional approach for project scheduling is the well-known CPM and, when taking a further step, the use of PERT to deal with uncertainty. However, these two traditional approaches have weaknesses in scheduling product development projects, particularly in terms of modeling iteration (Qian and Goh, 2007).

With regard to the work flow of activities, the CPM approach loses effectiveness when it seeks to deal with iterative processes or handle coupled activities in sequent or parallel activities (Oloufa et al., 2004). Although traditional project management tools like PERT and Gantt charts are useful in sequencing discrete activities or tasks in complex construction projects, they cannot manage the back-and-forth exchange of information that usually occurs in product development projects (Eppinger, 2001).

The DSM approach, developed by Steward (1981), is useful in representing complex relationships of dependency caused by information exchange between activities (Yassine and Braha, 2003). Differing from the traditional CPM approach, DSM represents information flows based on workflows in a project, which can handle not only sequential, parallel activities, but also coupled activities (Oloufa et al., 2004). With the use of such a tool for describing information flow, the relationship of information dependency between activities would make analysis and decision making easier (Maheswari et al., 2006). In comparison to all other graph-based tools, the DSM provides a simpler and clearer visual description of complex systems (Luh et al., 2009; Sharif and Kayis, 2007).

Increased use of DSM can be found in different contexts, from product development, project planning, and systems engineering to organizational design (Browning, 2001), particularly regarding organizing design tasks (Qian and Goh, 2007).

The DSM approach, together with other tools and techniques, could be widely employed to solve different types of problems in various kinds of projects; e.g., DSM can be integrated with quality function deployment (QFD) to support design planning for new product development projects (Hung et al., 2008); be integrated with Cognitive Maps to overcome communication problems and to ease knowledge sharing of design projects; or be integrated with the Monte Carlo Simulation to facilitate change management of construction projects (Zhao et al., 2010). In addition, DSM can be transformed to other matrices in different scenarios of project management; e.g., Avritzer et al. (2010) transformed DSM into a Communication Matrix (COM) to handle coordination issues, and Senthilkumar et al. (2010) transformed DSM into Design Interface Management Matrices (DIMM) to solve the problem of interface management. The robust technique of the Work Transformation Matrix (WTM), proposed by Cronemyr et al. (2001), is also an extension of DSM.

Browning (2001: 293) classified DSMs into four types according to their application: 1) component-based or architecture DSM, which is useful for modeling system component relationships and facilitating appropriate architectural decomposition strategies; 2) team-based or organization DSM, which is beneficial for designing integrated organization structures that account for team interactions; 3) activity-based or schedule DSM, which is advantageous for modeling the flow of information among process activities; and 4) parameter-based (or low-level schedule) DSM, which is effective for integrating low-level design processes based on physical design parameter relationships. Each of these four types of DSMs is, to some degree, related to project management. According to Mohan (2002), DSM is useful for identification, definition, recording, and examination of intrinsic system dependencies at different levels from projects to programs, not only in development phases but also in operational phases.

However, based on a survey that systematically classified the approaches used in DSM-based process planning, Karniel and Reich (2009: 636) identified a gap in the literature regarding “activities sequencing based on DSM and the process modeling literature concerning process verification.” They claimed that, “the DSM itself does not express all the relevant information required for defining process logic. Many logic interpretations are applicable in different business cases; yet, a consistent method of transforming a DSM-based plan to a logically correct concurrent process model in the case of iterative activities is lacking.”

In addition, DSM requires effort and skilled personnel to estimate information dependency attributes. The estimation efforts have a negative effect on the use of this method (Maheswari et al., 2006). Nevertheless, although a traditional

DSM may provide a relatively efficient analytical method with which to describe the information dependency of project activities, it cannot effectively represent the vagueness and uncertainty of dependency between two activities. In such cases, fuzzy approach needs to be integrated (Luh et al., 2009). Therefore, in this paper, we develop a novel framework that integrates fuzzy set theory and DSM to solve the problem of vagueness and uncertainty of information dependency for project scheduling.

3. The proposed fuzzy approach of DSM-based project scheduling

3.1. Traditional algorithm of DSM-based scheduling

The traditional algorithm of DSM-based scheduling can be performed in two ways. One is executed as the user estimates the normal project duration by capturing the communication time along with the work done for each activity, which does not take the overlapping between activities into consideration. The other is performed by integrating the overlapping into the calculation of project scheduling. In this paper, we address the latter process, which is more complicated and relatively near practice. Maheswari and Varghese (2005), on the base of former research of Krishnan et al. (1997), proposed an approach for DSM-based project scheduling, with consideration for overlapping. In this approach, the time factor of information exchange along with the duration for each activity and their relationship is represented in two separate matrices: B_{ij} (for all predecessor activities) and C_{ij} (for all the successor activities), which is shown in Fig. 1. The algorithm is as follows:

$$(ES)_j = Max[(ES)_i + (B_{ji} \times B_{ii}) - (C_{ji} \times C_{jj})] \quad 0 < i \leq n, 0 < j \leq n \tag{1}$$

$$(EF_j) = (ES_j) + C_{jj} \quad 0 < j \leq n \tag{2}$$

$$T_{total} = Max[(EF_j)] \quad 0 < j \leq n \tag{3}$$

where n is the number of activities, i all the (immediate) predecessors of j, j the current activity chosen in the order as identified by partitioned DSM, ES the early start, EF the early finish, and T_{total} the project duration. In addition,

$$B_{ji} = P_1/P_2; C_{ji} = S_1/S_2 \tag{4}$$

where P represents all the (immediate) predecessor activities, and S represents all the (immediate) successor activities. Shown in Fig. 1, P_1 is the units of time that are required to release the information from activity P, P_2 is the duration of P, S_1 is the unit of time that S can be executed without the information of P, and S_2 is the duration of S. $S_2 - S_1$ is the unit of time in which S needs to be executed after receiving the information from P. (e.g. the immediate predecessor activity is the architectural design of a house, the immediate successor activity is the structural design of a house. Then P_1 refers to the unit of time that the architect requires to provide enough information for structural design. S_2 refers to the unit of time that the structure engineer can work without the information of architectural design, such as the collection of materials of geological conditions and etc.).

3.2. The proposed fuzzy approach

In the traditional DSM-based project scheduling approach, one present problem is that the time factors of information exchange are difficult to determine during the planning stage of a project, even if we hold a meeting with a group of experts. When asked to estimate the time factors of information exchange based on similar previous projects, it is difficult for the experts to give a precise time, especially for irregular projects such as NPD or organizational change. In such cases, it is much more reasonable and practical for the experts to give a fuzzy number (or linguist variable) rather than a certain one. Therefore, the fuzzy approach needs to be integrated to solve the vague problem related to time factors of information exchange between activities.

With regard to dealing with imprecise problems in project scheduling, Liberatore (2008) proposed an approach for critical path analysis using fuzzy activity times. The membership function for the fuzzy critical path can be described as follows:

$$\begin{gathered} \mu_{cp}(L_{cp}) = MaxMin\{\mu_i(t_i)\} \\ t_1, t_2, ..., t_N, i \in \{1, 2, ..., N\} \\ f(t_1, t_2, ...t_n | G) = L_{cp} \end{gathered} \tag{5}$$

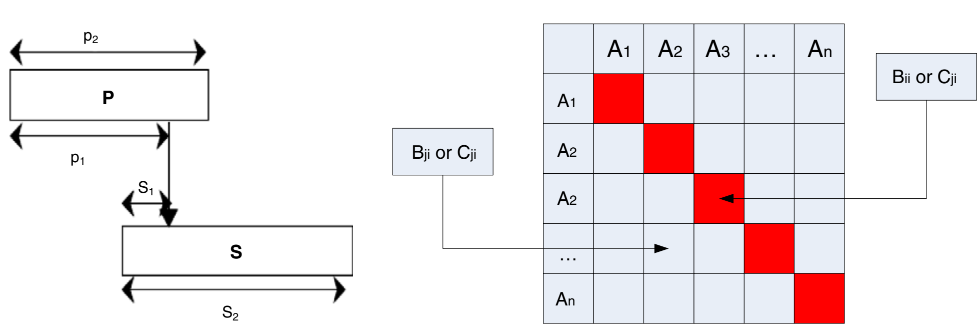

Fig. 1. Transfer of information for the predecessor activity P and the successor activity S.

where $\mu_{CP}(L_{CP})$ is the membership function for the length of the critical path over the fuzzy subset CP and for a graph G, and activity durations $t_1, t_2, \ldots, t_N$, $f(t_1, t_2, \ldots, t_N|G)$ determine the length of the critical path. In addition, the membership function for S_i is determined as follows:

$$\begin{aligned}&\mu_{s_i}(S_i) = MaxMin\{\mu_i(t_i)\}\\ &t_1, t_2, \ldots, t_N, i \in \{1, 2, \ldots, N\}\\ &g(t_1, t_2, \ldots t_n|G) = S_i\end{aligned} \tag{6}$$

where S_i is the slack of activity when $S_i = 0$, $\mu_{Si}(0)$ is defined as the fuzzy criticality of activity i.

The algorithm can be converted to nonlinear to programming problem for the final solution.

In order to make the problem simpler and easier for application, the fuzzy duration of activities can described as discretized trapezoidal numbers or triangular fuzzy numbers. Chen and Huang (2007) proposed an approach through which to determine the critical degrees of activities and paths in a fuzzy environment of project scheduling by using triangular fuzzy numbers. A case example shows that triangular fuzzy numbers are very suitable for describing the PERT problem for fuzzy scheduling.

In this paper, we also employ the triangular fuzzy numbers to describe the vagueness of time factors of information transfer between activities. The membership function of a positive triangular fuzzy number $\tilde{T} = (\mathrm{l}, \mathrm{m}, \mathrm{u})$ can be defined as follows:

$$u_{\tilde{T}}(x) = \begin{cases}\dfrac{x-l}{m-l}, l \le x \le m\\ \dfrac{u-x}{u-m}, m \le x \le u\\ 0, \text{otherwise}\end{cases} \tag{7}$$

where $l < 0$. If two positive triangular fuzzy number are $\tilde{T}_1 = (l_1, m_1, u_1)$ and $\tilde{T}_2 = (l_2, m_2, u_2)$, referring to Kaufmann and Gupta (1991) and Liang and Wang (1993), the operators between them are defined as follows:

$$\begin{aligned}&\text{Addtion}\oplus: \tilde{T}_1 \oplus \tilde{T}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)\\ &\text{Substraction}\Theta: \tilde{T}_1 \Theta \tilde{T}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2)\\ &\text{Multiplication}\otimes: \tilde{T}_1 \otimes \tilde{T}_2 \approx (l_1 l_2, m_1 m_2, u_1 u_2)\\ &\qquad h \otimes \tilde{T}_1 = (hl_1, hm_1, hu_1)\\ &\text{Division}\Phi: \tilde{T}_1 \Phi \tilde{T}_2 \approx (l_1/u_2, m_1/m_2, u_1/l_2).\end{aligned} \tag{8}$$

In the practical application, there are two scenarios that can lead to two types of different algorithm. In one scenario, the time factor of information exchange between activities is vague while the activity duration is certain. In another scenario, both of them are vague. In actuality, the first scenario is just a specific case of the second. Therefore, we address the problem of the second scenario in this paper. Then the fuzzy algorithm of DSM-based earliest start/finish time of each activity, transformed from Eqs. (1) and (2), is as follows:

$$\begin{aligned}&\left(\tilde{ES}\right)_j = \text{Max}\left[\left(\tilde{ES}\right)_i \oplus \left(\tilde{B}_{ji} \otimes \tilde{B}_{ii}\right) \Theta \left(\tilde{C}_{ji} \otimes \tilde{C}_{jj}\right)\right]\\ &0 < i \le n, 0 < j \le n\end{aligned} \tag{9}$$

$$\left(\tilde{EF}_j\right) = \left(\tilde{ES}_j\right) \oplus \tilde{C}_{jj} \quad 0 < j \le n. \tag{10}$$

The latest start/finish time for each activity (based on the STS overlap relationship) can be described as follows:

$$\begin{aligned}&\left(\tilde{LS}\right)_i = \text{Min}\left[\left(\tilde{LS}\right)_j \oplus \left(\tilde{C}_{ji} \otimes \tilde{C}_{jj}\right) \Theta \left(\tilde{B}_{ji} \otimes \tilde{B}_{ii}\right)\right]\\ &0 \le i < n, \ 0 < j < n\end{aligned} \tag{11}$$

$$\left(\tilde{LF}_j\right) = \left(\tilde{LS}_j\right) \oplus \tilde{B}_{ii} \quad 0 < j \le n. \tag{12}$$

In addition, the earliest start time of the initial activity is $\tilde{ES}_{\text{start}} = (0, 0, 0)$; the latest finish time is equal to the earliest finish time for the end activities, denoted by $\tilde{LF}_{\text{end}} = \tilde{EF}_{\text{end}} = D_{\text{cp}}$, where D_{cp} is the duration of the critical path, and viz the project duration.

The fuzzy total slack time (or total float time) of each activity is as follows:

$$\tilde{S}_i = \tilde{LS}_i \Theta \tilde{ES}_i. \tag{13}$$

In traditional CPM, activity i is regarded as a critical activity if its float time is zero. Taken a further step, based on the rule that criticality rises as fuzzy float time decreases, Chen and Huang (2007) proposed an approach to define the criticality of an activity as follows:

If the fuzzy float time of activity i is $\tilde{S}_i = (a_i, b_i, c_i)$, then the criticality of this activity is defined as follows:

$$CD_i = \begin{cases}1 & b_i \le 0\\ -a_i \big/ b_i - a_i & a_i < 0 < b_i\\ 0 & a_i \ge 0\end{cases} \tag{14}$$

where CD_i is the critical degree of activity i. However, this definition does not take c_i into consideration. In fact, the value of c_i does, to some degree, affect the CD of an activity. Therefore, we propose an approach that integrates the influence of c_i. Here we introduce an intermediate variable, V_i, which is as follows:

$$V_i = \begin{cases}1 & c_i \le 0\\ \dfrac{a_i^2}{(b_i - a_i)(c_i - a_i)} & a_i < 0 \le b_i\\ 1 - \dfrac{c_i^2}{(c_i - b_i)(c_i - a_i)} & b_i < 0 < c_i\\ 0 & a_i \ge 0\end{cases}. \tag{15}$$

Then the CD of an activity is defined based on the following rule:

If $V_i \ge 0.5$ then $CD_i = 1$; if $V_i < 0.5$, then $CD_i = 2 \times V_i$ $(0 \le CD_i \le 1)$.

According to the CD of an activity, the CD of a path is defined as follows:

$$CD(P_k) = \min\{CD_i\} \quad (i \in P_k) \tag{16}$$

where P_k is the kth path in the network. In addition, the project duration equals the length of the path that has the largest critical degree, which is also a triangular fuzzy number.

In general, the steps to perform the algorithm for DSM-based project scheduling by fuzzy approach should be: (1) Use DSM to show the dependency of information between activities, in which the vagueness of time factors, viz $\tilde{B}_{ji}$ and $\tilde{C}_{ji}$, for information exchange, are described by triangular fuzzy numbers; (2) Calculate the $\tilde{ES}$ and $\tilde{EF}$ of each activity using Eqs. (9) and (10) and the $\tilde{LS}$ and $\tilde{LF}$ of each activity using Eqs. (11) and (12); (3) Calculate the slack time of each activity using Eq. (13). Afterwards, calculate the CD of the each activity based on the fuzzy value of the slack time using Eq. (15); and (4) calculate the CD of each path using Eq. (16).

4. An example

In this section, an example is presented to show how to use the proposed approach to solve the vagueness in DSM-based scheduling. We have chosen a design project of a special equipment that includes 16 core components. For dealing with large scale projects with thousands of activities, we may utilize milestones to decouple the network into a series of small ones. In this project, the dependent relationships of information between the design activities of each component are shown in Table 1. In the first column, activities A to Q represent the design tasks of components A to Q. R is the final integrated design task of the equipment. In the second column, the duration of each activity is shown by a triangular fuzzy number. The dependent relationships of information are shown in the third column, e.g. the predecessor activity of D is A. If we describe this project by using a network diagram, it includes 18 nodes. The order strength (OS), which measures the complexity of the network, is 0.48.

Table 1
Relationship of information dependency.

Activity name	Duration (days)	Information predecessors
Start	0, 0, 0	–
A	5, 6, 8	Start
B	3, 4, 6	Start
C	4, 5, 6	Start
D	2, 3, 4	A
E	1, 2, 4	A, B, C
F	2, 3, 4	C
G	5, 6, 7	D
H	3, 4, 6	E
I	1, 2, 4	E, F
J	6, 7, 8	G
K	1, 2, 3	G, H, I
L	2, 4, 5	I
M	1, 2, 4	A
N	2, 3, 4	M, D
P	3, 4, 5	C
Q	2, 3, 5	P
R(Finish)	8, 8, 8	J, K, L, N, Q

(1) The value of time factors of B_{ji} and C_{ji} of each activity is shown separately in Fig. 2(a) and (b), which is transformed from linguistic variables.
The rule of the transformation from linguistic variable to triangular fuzzy numbers is as follows, shown in Fig. 3: In detail, for B_{ji} in matrix No. 1 and C_{ji} in matrix No. 2, the linguistic variables are described in Table 2:
(2) The ES, EF, LS, and LF of each activity are calculated and are shown in Table 3.
(3) Calculate the slack time of each activity and the critical degree of each activity. The result is shown in Table 3.
(4) Calculate the CD of each path. The result is shown in Table 4. With a critical degree of 1, Path Sta-A-D-G-J-R(Fin.) is the most important one for the schedule control of this design project.

5. Further discussion of the proposed algorithm

(1) This DSM-based fuzzy algorithm for project scheduling can be used in different ways. According to the CD of an activity and its path, it is easy for us to determine which needs to be crashed in order to shorten the project duration, as stated by Chen and Huang (2007). Moreover, with regard to the fuzzy project duration, we can make a relatively reasonable decision for the external project when submitting a bid. On the other hand, we may integrate the fuzzy project duration with elements of the financial analysis, such as pay pack period and ROI, for internal projects.
(2) The triangular fuzzy number of time factors in this algorithm is based on the description of linguist variables shown in Table 2. The classification and definition can be divided into smaller intervals when necessary. In addition, if the value can be estimated precisely, the triangular fuzzy number turns to a certain one such as (1, 1, 1) or (0, 0, 0), as shown in the example.
(3) The calculation of critical degree factor proposed in Eq. (15) is based on the distribution of membership function of triangular fuzzy numbers. We may also use other approaches to calculate the value of CD; e.g., based on the degree of the variance of Center of Gravity (COG) from the zero line, etc.
(4) Here we have assumed that the information exchange occurs only once between any two activities. If the information is actually exchanged between activities several times, we can break the activities into “n” numbers of sub-activities to retain the assumption of single information exchange as argued by Maheswari and Varghese (2005).
(5) Considering the rework of activities, we can use the fuzzy duration of activities to deal with uncertainties. Moreover, if the information dependency of activities is uncertain, we may use the clustering method to quantify the relationship of coupled activities (Liang, 2009; Luh et al., 2009).

a) Matrix No. 1—Bij

	STA	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q	FIN
STA																		
A	1,1,1																	
B	1,1,1																	
C	1,1,1																	
D		0.8 0.9 0.9																
E		0.6 0.7 0.8	0.8 0.9 0.9	0.4 0.5 0.6														
F				0.6 0.7 0.8														
G					0.8 0.9 0.9													
H						0.6 0.7 0.8												
I						0.8 0.9 0.9	0.4 0.5 0.6											
J								0.6 0.7 0.8										
K								0.8 0.9 0.9	0.6 0.7 0.8	0.4 0.5 0.6								
L										0.8 0.9 0.9								
M		0.6 0.7 0.8																
N					0.8 0.9 0.9									0.6 0.7 0.8				
P				0.8 0.9 0.9														
Q																0.8 0.9 0.9		
R(FIN)											0.8 0.9 0.9	0.6 0.7 0.8	0.8 0.9 0.9		0.8 0.9 0.9		0.6 0.7 0.8	

b) Matrix No. 2—Cij

	STA	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q	FIN
STA																		
A	0,0,0																	
B	0,0,0																	
C	0,0,0																	
D		0.1 0.1 0.2																
E		0.2 0.3 0.4	0.1 0.1 0.2	0.1 0.1 0.2														
F				0.2 0.3 0.4														
G					0.4 0.5 0.6													
H						0.1 0.1 0.2												
I						0.2 0.3 0.4	0.1 0.1 0.2											
J								0.2 0.3 0.4										
K								0.1 0.1 0.2	0.2 0.3 0.4	0.1 0.1 0.2								
L										0.1 0.1 0.2								
M		0.2 0.3 0.4																
N					0.2 0.3 0.4									0.2 0.3 0.4				
P				0.1 0.1 0.2														
Q																0.1 0.1 0.2		
R(FIN)											0.1 0.1 0.2	0.2 0.3 0.4	0.1 0.1 0.2		0.1 0.1 0.2		0.1 0.1 0.2	

Fig. 2. The relationship of information dependency described by DSM. (a) Matrix No. 1—Bij. (b) Matrix No. 2—Cij.

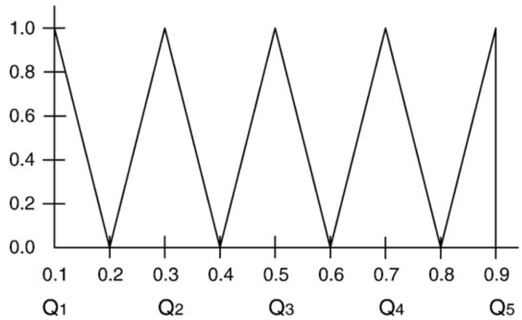

Fig. 3. Linguist variables and triangular fuzzy number.

6. Conclusion and future research

We have proposed a fuzzy approach for DSM-based project scheduling to address the problem that the overlap caused by the vagueness and impreciseness of information dependency between activities. This algorithm can be regarded as an extension of the traditional algorithm of DSM-based scheduling proposed by Maheswari and Varghese (2005), which is particularly useful in dealing with fuzzy issues of information dependency. Moreover, with regard to the management of projects such as new product development or collaborative design, information flow is a very important determinant in scheduling. Therefore, with its special purpose to solve the problem of fuzzy interdependent relationships between activities caused by information flow rather than general work flow, this algorithm can also be regarded as another branch of fuzzy approaches for project scheduling, which is different from the former CPM&PERT-based fuzzy algorithms proposed by Chen and Huang (2007), Chen and Hsueh (2008), and Liberatore (2008).The strength of this fuzzy algorithm is that it can be referred to analyze the critical degree of activities, paths, and to a further degree, the duration of a project within an uncertain environment of information dependencies between activities.

However, as a matter of fact, for some complex projects the problems of project scheduling are far more extensive than just the arrangement of activity sequence. Project scheduling is also related to the issue of resource allocation, organizational structure, and behaviors of stakeholders that may affect the information sharing mechanism among different project partners. Moreover, other goals of project management such as cost and quality need to be considered in project time management. Therefore, there still exist limits of the practical application of this approach. For the next step we will conduct further

Table 2
Description of linguistic variables of B_{ji} and C_{ji} using triangular fuzzy number.

	Bji	Cji
Q_1 (0.1, 0.1, 0.2)	Required information can be released after a small percentage of work has been finished.	A little work can be conducted before the information is released from its predecessor activity.
Q_2 (0.2, 0.3, 0.4)	Required information can be released after a percentage of work has been finished.	Some work can be conducted before the information is released from its predecessor activity.
Q_3 (0.4, 0.5, 0.6)	Middle status	Middle status
Q_4 (0.6, 0.7, 0.8)	Required information can be released after a large amount of work has been finished.	A large amount of work can be conducted before the information is released from its predecessor activity.
Q_5 (0.8, 0.9, 0.9)	Required information can be released after almost all the work has been finished.	Almost all the work can be conducted before the information is released from its predecessor activity.

Table 3
Calculation results of time variables and CD of each activity.

Activity name	ES	EF	LS	LF	Slack (float)	CD
Sta.	0, 0, 0	0, 0, 0	−15.8, 0, 15.8	−15.8, 0, 15.8	−15.8, 0, 15.8	1
A	0, 0, 0	5, 6, 8	−15.8, 0, 15.8	−10.8, 6, 23.8	−15.8, 0, 15.8	1
B	0, 0, 0	3, 4, 6	−12.2, 3.6, 18.8	−9.2, 7.6, 24.8	−12.2, 3.6, 18.8	0.61
C	0, 0, 0	4, 5, 6	−10.4, 3.7, 16.2	−6.4, 8.7, 22.2	−10.4, 3.7, 16.2	0.58
D	3.2, 5.1, 7	5.2, 8.1, 11	−8.8, 5.1, 19	−6.8, 8.1, 23	−15.8, 0, 15.8	1
E	1.6, 3.6, 6.2	2.6, 5.6, 10.2	−6.9, 7, 20.4	−5.9, 9, 24.4	−13.1, 3.4, 18.8	0.65
F	0.8, 2.6, 4.4	2.8, 5.6, 8.4	−5.8, 6.9, 19.6	−3.8, 9.9, 23.6	−10.2, 4.3, 18.8	0.49
G	0.6, 4.8, 8.6	5.6, 10.8, 15.6	−7.2, 4.8, 16.4	−2.2, 10.8, 23.4	−15.8, 0, 15.8	1
H	1, 4.6, 9.1	4, 8.6, 15.1	−1.8, 11.2, 21.4	1.2, 15.2, 27.4	−10.9, 6.6, 20.4	0.43
I	0.8, 4.8, 9.6	1.8, 6.8, 13.6	−3.5, 8.2, 19.6	−2.5, 10.2, 23.6	−13.1, 3.4, 18.8	0.65
J	0.4, 6.9, 13	6.4, 13.9, 21	−2.8, 6.9, 16.2	3.2, 13.9, 24.2	−15.8, 0, 15.8	1
K	4, 10, 14.8	5, 12, 17.8	2.8, 13.4, 22	3.8, 15.4, 25	−12, 3.4, 18	0.62
L	0.6, 6.2, 13	2.6, 10.2, 18	−0.1, 9.6, 19.4	1.9, 13.6, 24.4	−13.1, 3.4, 18.8	0.65
M	1.4, 3.6, 6.2	2.4, 5.6, 10.2	−2, 10, 20.4	−1, 12, 24.4	−8.2, 6.4, 19	0.34
N	3.2, 6.9, 10.2	5.2, 9.9, 14.2	0.8, 10.5, 19.4	2.8, 13.5, 23.4	−9.4, 3.6, 16.2	0.53
P	2.2, 4.1, 5.1	5.2, 8.1, 10.1	−3.9, 7.8, 18.4	−0.9, 11.8, 23.4	−9, 3.7, 16.2	0.51
Q	3.6, 7.4, 9.4	5.6, 10.4, 14.4	0.4, 11.1, 19.8	2.4, 14.1, 24.8	−9, 3.7, 16.2	0.51
R(Fin.)	3.6, 12.4, 19.4	11.6, 20.4, 27.4	3.6, 12.4, 19.4	11.6, 20.4, 27.4	−15.8, 0, 15.8	1

Table 4
Critical degree of each path.

Path	Critical degree
Sta-A-M-N-R(Fin.)	0.34
Sta-A-D-N-R(Fin.)	0.53
Sta-A-D-G-J-R(Fin.)	1
Sta-A-D-G-K-R(Fin.)	0.62
Sta-A-E-H-K-R(Fin.)	0.43
Sta-A-E-I-K-R(Fin.)	0.62
Sta-A-E-I-L-R(Fin.)	0.65
Sta-B-E-H-K-R(Fin.)	0.43
Sta-B-E-I-K-R(Fin.)	0.61
Sta-B-E-I-L-R(Fin.)	0.61
Sta-C-E-H-K-R(Fin.)	0.43
Sta-C-E-I-K-R(Fin.)	0.58
Sta-C-E-I-L-R(Fin.)	0.58
Sta-C-F-I-K-R(Fin.)	0.49
Sta-C-F-I-L-R(Fin.)	0.49
Sta-C-P-Q-R(Fin.)	0.51

research that integrates other approaches in the field of DSM-based scheduling with consideration for the trade-off between time and other goals of project management.

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