A Structured Approach to Form Dependency Structure Matrix for Construction Projects

J. Uma Maheswari, and Koshy Varghese

Abstract— The sequence of design activities is vital, particularly in interdisciplinary projects. Sequencing of activities is influenced by the information dependency among the activities. The dependency relationships among the design activities in a project are of three types – independent, dependent and interdependent or loops. Interdependent activities (or loops) require assumed information to start and progress. If these assumptions are erroneous, it can lead to rework of a single or a group of dependent activities. One of the challenges in planning the sequencing of design activities is to decide on appropriate information or assumptions which can be made to break the interdependent activities (or loops).

Conventional tools such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) are not suitable for representing information flow because interdependent activities or loops cannot be modeled. Dependency Structure Matrix (DSM) has been identified as a potential tool to model feedback loops/ cycles. One of the main difficulties in implementing DSM is in comprehensively identifying the activities and information dependencies which are required to formulate the DSM. Based on the experience in attempting to develop a DSM for an interdisciplinary project, the authors have proposed a new approach in identifying all the possible activities and their information dependencies.

A prototype software also had been developed in Excel VBA for implementing the methodology. The proposed concepts are illustrated through application to Induced Draft Cooling Tower (IDCT) projects. This illustration is multidisciplinary in nature consisting of mechanical, civil, electrical and instrumentation. The proposed concept has proven fruitful and hence this approach is anticipated beneficial for construction applications.

***Index Terms*— Dependency Structure Matrix, Project Planning, Information Flow, Construction Design Projects.**

I. Introduction

SEQUENCING interdisciplinary design activities is an important but challenging problem. The problem is important as reduction of design duration through appropriate sequencing will facilitate earlier completion of the project. It has been found that sequencing of design activities is influenced by the *information dependency* among the activities [1]. The dependency relationships among the design activities in a project are of three types – independent, dependent and interdependent or loops as shown in Fig. 1 [2]. If the project activities are interdependent (or loop), they require assumed information to start and progress. If these assumptions are erroneous, it can lead to rework of a single or a group of dependent activities. One of the challenges in planning the sequencing of design activities is to decide on the assumptions and the corresponding sequence of execution, which will result in little risk of errors and rework.

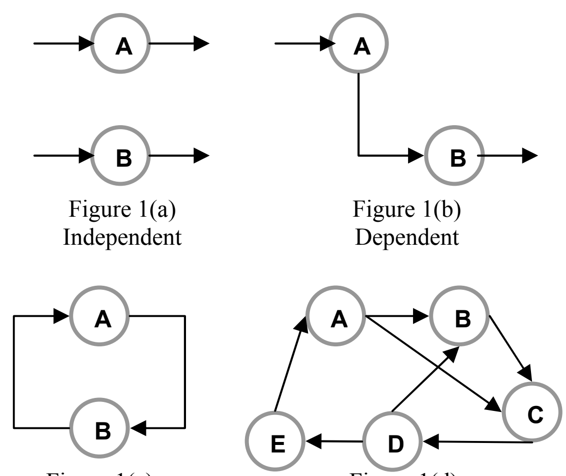

Figure 1(a) Independent

Figure 1(b) Dependent

Figure 1(c) Interdependent

Figure 1(d) Cycles/ Loops

Fig. 1 Dependency Relationship among the Activities

Conventional tools such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) are not suitable for representing information dependencies because interdependent activities or loops cannot be modeled [1]-[3]. *Dependency Structure Matrix (DSM)* has been identified as a potential tool to model interdependent activities (or loops), to identify suitable assumptions, formulate and evaluate the resulting sequence [1], [3], [4].

The basic representation of Activity DSM is a *square* matrix containing a list of activities in the rows and columns in the same order. The order of activities in the rows or columns indicates the *execution sequence*. The relationships among the activities are represented with the help of 'X' marks in the off-diagonal cells. An 'X' mark above the

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diagonal indicates that an assumption of information is required to start the activity. Fig. 2(a) shows a basic DSM for six activities.

The process of rearranging the order of activities in such a way that the dependency relationships are brought either below the diagonal or close to the diagonal and the formation of blocks is called *partitioning*. Fig. 2(b) shows the partitioned DSM. Analyzing the project, few dependency relationships are temporarily removed by making assumptions. This process is referred as *tearing* and Fig. 2(c) represents the DSM with tear marks. Once the assumptions are made through tearing, the matrix is repartitioned for determining the *preferred* execution sequence as illustrated in the Fig. 2(d).

	A	B	C	D	E	F
A			X			
B					X	
C	X					X
D		X			X	
E			X			
F	X		X		X	

Figure 2(a)
Activity DSM

	A	C	E	F	B	D
A		X				
C	X			X		
E		X				
F	X	X	X			
B			X			
D			X		X	

Figure 2(b)
Partitioned DSM

	A	C	E	F	B	D
A		X				
C	X			X		
E		X				
F	X	X	X			
B			X			
D			X		X	

Figure 2(c)
Tearing Process

	C	A	E	F	B	D
C		X		X		
A	X					
E	X					
F	X	X	X			
B			X			
D			X		X	

Figure 2(d)
Repartitioned DSM

Fig. 2 DSM Operations

In the above process of project planning, formation of activity DSM itself is a challenging task. Failure to identify either an activity or a dependency relationship may result in incorrect representation of the project. Hence the benefit of DSM planning will not be achieved. Therefore, the present study focuses on defining a structured approach to form an activity DSM.

A software prototype tool has been developed using Excel VBA (Visual Basic for Applications). The suggested methodology was applied to a design component of Induced Draft Cooling Tower (IDCT) project – cases collected from L&T-ECC (Larsen & Toubro Ltd), a leading construction organization in India. The results from this application are analyzed and discussed.

II. RELEVANCE FROM PAST STUDY

A. Types of DSM

DSM can be classified into four types based on the choice of element along the rows and columns as team-based DSM, component DSM, activity DSM and parameter DSM [1], [3]. A variation of DSM (rectangular matrix which signifies different type of elements for rows and columns) was proposed with combination of elements along the rows and columns [5]. This variation was found beneficial to product developers, project planners, project managers, system engineers, and organizational designers and the variable DSM was the Design Process Matrix (DPM).

Hence, for effective project planning mapping the *interactions* among team, component, activities or parameters is essential.

B. Information Flow/ Access

Complex Interactions can be managed effectively through decompositions of the system into elements and documenting the interactions between the elements by transforming a conceptual idea into a finished product [6], [7]. The interactions among a network of tasks in any system can be of material, energy and information between and among the system [8]. Among the above transactions, exchange of information among a large number of dependent or interdependent tasks and team members is considered critical for effective project planning [9].

Designer's conception of a design is generally built up over time, using information from the designer's prior knowledge and experience, and from external sources of information [10]. The selection of an information source will depend on the type of activity the designer is performing. Access to such information will be essential if the information can be provided during early stages of the design process [11].

Therefore, for effective project planning managing the information exchange among the activities is required.

C. Formation of DSM

DSM models are difficult to build, especially during the initial stages, as they depict data (or information) that are not always at hand, easily gathered, or quickly assimilated [12]. The main source of difficulty to visualize and capture the information relationships is the lack of efficient models for capturing all the elements and their interdependencies in a single, but simple, way [13].

Conventional DSM formation utilizes a hybrid approach relying on existing documentation/ reports and interviews with experts from various functional groups [1], [3]. Since this was not effective to capture all the relationships, a new matrix-based technique called the 'connectivity map' was developed for capturing and analysing relations between development tasks, design parameters, architecture concepts, information flows, and organizational relationships as seen in

Fig. 3 [13]. Even though the connectivity maps capture the logic behind the dependency relationships, they are not easy to develop, especially for new DSM users due to many relationship matrices as in Fig. 3.

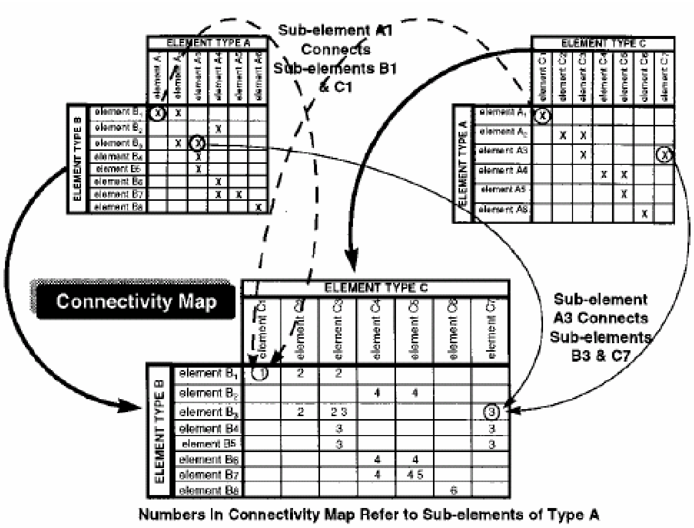


Fig. 3 Connectivity Map [13]

D. Construction Applications

Although extensive research on the application of DSM has been carried out in manufacturing by the research groups at MIT (Massachusetts Institute of Technology), UIUC (University of Illinois at Urbana-Champaign) and few others, little work has been done in construction. Construction researchers in Loughborough University and in VTT (Technical Research Centre of Finland) have demonstrated through case studies that DSM can be used to find better sequences for building design process [14]-[17].

ADePT (Analytical Design Planning Technique) creates a model of the design process and sorts individual design tasks into the optimum sequence helping to deliver better building design [16]-[17]. The DPM (Design Process Model) of detailed building design process was developed by identifying the activities and their hierarchical structure and determining the information requirements for each activity. A sample DPM is as shown in the Fig. 4

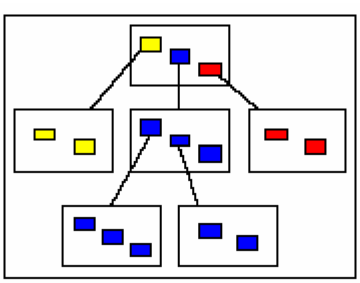


Fig. 4 Design Process Model [16]

Since the above model was developed for building design process, it was not powerful when applying for multidisciplinary projects with numerous interactions. Hence, there arose a need for an alternate methodology to define the activity DSM.

E. Need for the Present Study

As discussed earlier, failure to identify either an activity or a dependency relationship may result in incorrect representation of the project and thereby the benefit of DSM planning will not be achieved. The main objective of the present study is to form a complete activity DSM through a structured approach utilizing WBS and capturing all the information relationships especially for new DSM users.

III. PROPOSED METHODOLOGY

As discussed in the earlier sections, formation of activity DSM is an involved task. Based on the experience in attempting to develop a DSM for an interdisciplinary project, a new approach has been proposed to identify the list of activities and their information dependencies. This approach utilizes Work Breakdown Structure (WBS) and information capture on teams/disciplines, components and activities as illustrated in Fig. 5.

For each activity, the lists of input and output parameters are determined and thereby two variable matrices are formed as in Fig. 6(a) and 6(b). There can be more than one output from a particular activity. Also, more than one input may be required for the execution of an activity. The activity DSM is formed by merging these two variable DSMs depicted through X marks as shown in the Fig. 6(c). This effort is targeted for new DSM users and is expected to form a complete DSM.

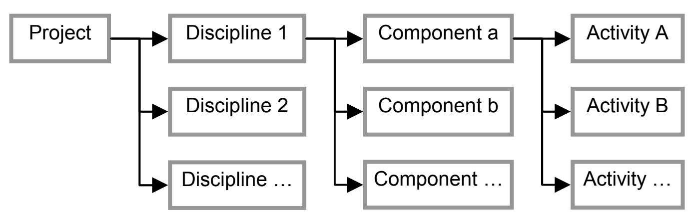


Fig. 5 Proposed Work Break Down Structure

	P 1	P 2	P 3	P 4	P 5	P 6
Act A	X					
Act B		X	X			
Act C				X	X	
Act D						X

Fig. 6(a) Variable DSM with Activities and Output Parameters

	P 1	P 2	P 3	P 4	P 5	P 6
Act A			X	X		X
Act B	X					
Act C		X				
Act D		X			X	

Fig. 6(b) Variable DSM with Activities and Input Parameters

	Act A	Act B	Act C	Act D
Act A		X	X	X
Act B	X			
Act C		X		
Act D		X	X	

Fig. 6(c) Activity DSM

Fig. 6 Formation of Activity DSM

IV. APPLICATION

The application of the proposed concepts was carried out with industry interaction for the Drive Assembly (DA) design of Induced Draft Cooling Tower (IDCT). IDCT projects require design expertise of four disciplines – mechanical, civil, electrical, and instrumentation. Each of these engineering processes was studied in detail through case-analysis of 5 projects and detailed discussions with the engineers and managers in the concerned field. The Drive Assembly (DA) design of IDCT being multidisciplinary in nature was chosen for the current study.

The above concepts had been modeled using Excel VBA. Once the prototype tool was ready, the proposed concepts were applied to DA component of IDCT project. The application on DA design was performed with detailed interactions and discussions with the L&T-ECC experts with the help of the prototype tool.

In the formation of activity DSM, the proposed structured approach was applicable in identifying all the activities and the relationships. The experts were able to list out the output parameters and the list of input parameters for each activity. On the other end, the conventional DSM formation required lot of interactions and discussions from the experts, especially to form the 'X' marks and required adequate knowledge on DSM. Further, for a sample of activities shown in the Fig. 6, two dependency relationships were missed out.

		DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP
Fan design	DA	3															
Motor design	DB	X	3	X													
Gear box design	DC		X	3													
Drive shaft design	DD		X		3												
Details of Equipment Handling System	DE	X	X	X		7											X
Details of removable walkway, handrail & trolley	DF						7				X						
Details of ladders, doors & hatches	DG	X	X	X				7			X						
Details of insert plates, anchor bolts	DH	X	X	X					7				X		X		X
Design of slabs, beams, pedestals at fan deck level	DI		X	X			X		X	7	X						
Design of fan stack & ring beams	DJ	X			X			X	X		7						X
Data Sheet of Level Switch	DK			X								2					
Instrument Location & Cable Routing Diagram	DL											X	6	X	X		
Data Sheet of Vibration Monitoring System	DM	X	X	X										2			
Cable trays, trench layout & sectional details	DN		X										X		3	X	
Illumination system (lighting) of CT	DO		X							X	X					2	
Earthing details & lightening protection	DP		X												X		2

Fig. 7 Activity DSM for DA component of IDCT project

Therefore, when the project is complex, with numerous information transfers, the proposed approach is beneficial in forming a complete activity DSM especially for new DSM users. This approach was also well received by the IDCT group. Fig. 7 shows the activity DSM for the complete DA design of IDCT.

The snapshots of the application are shown in the following Figs. 8 to 14. Once the project details are given as in the Fig. 8, the discipline form enables to define the list of disciplines for the project as Civil, Mechanical, etc as illustrated in Fig. 9. New disciplines can also be added as in the Fig. 9. For each discipline, list of components had to be defined as fan, motor, etc. as shown in Fig. 10. Similarly, the design activities are defined for the components as in Fig. 11, and for each activity, the output and input parameters are listed as illustrated in Fig. 12. These inputs lead to the tree formation as in Fig. 13 and the corresponding activity DSM will be formed as in Fig. 14.

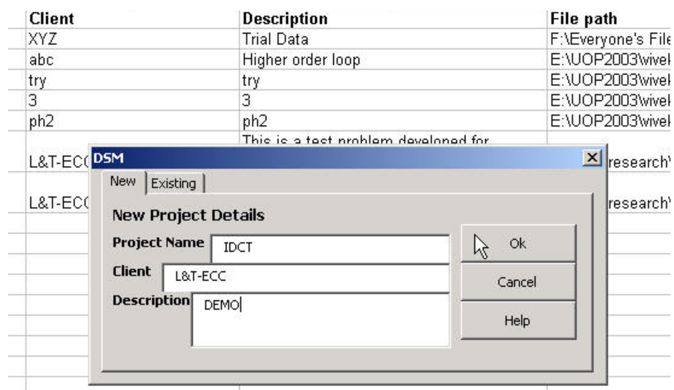


Fig. 8 Project Description

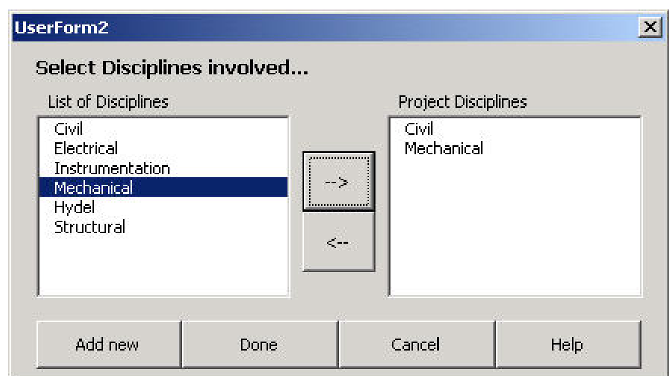


Fig. 9 Selection of Discipline

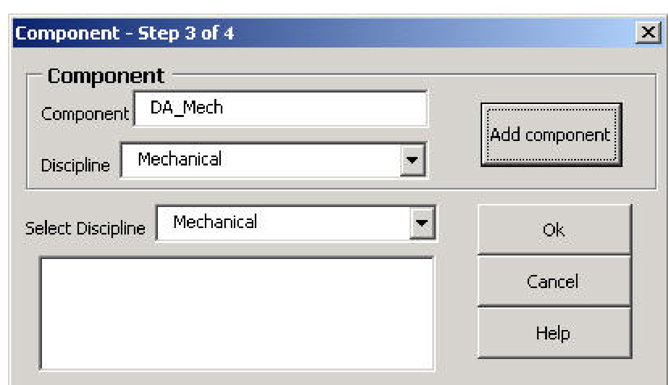


Fig. 10 Selection of Components

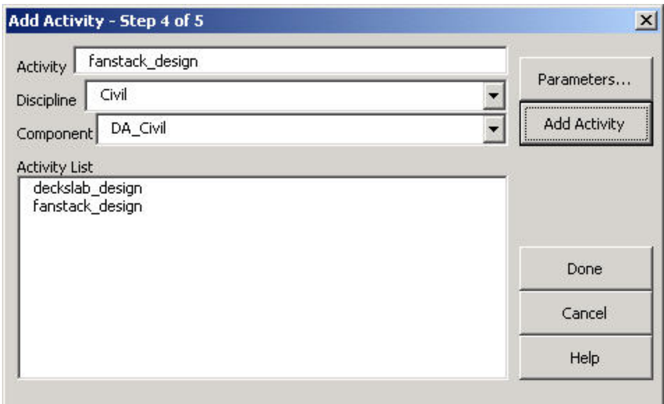


Fig. 11 List of Activities

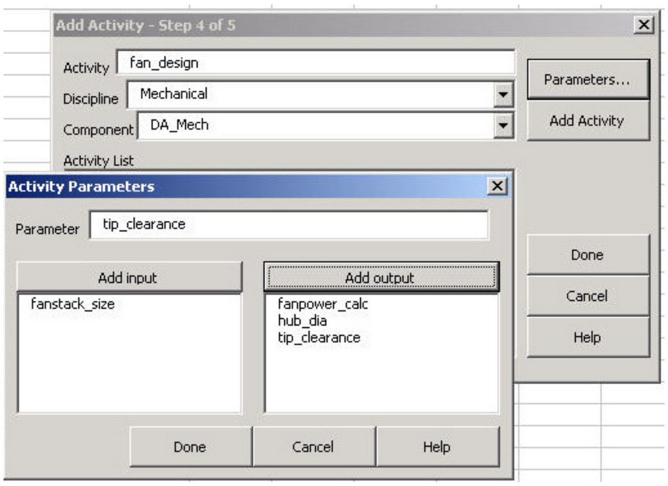
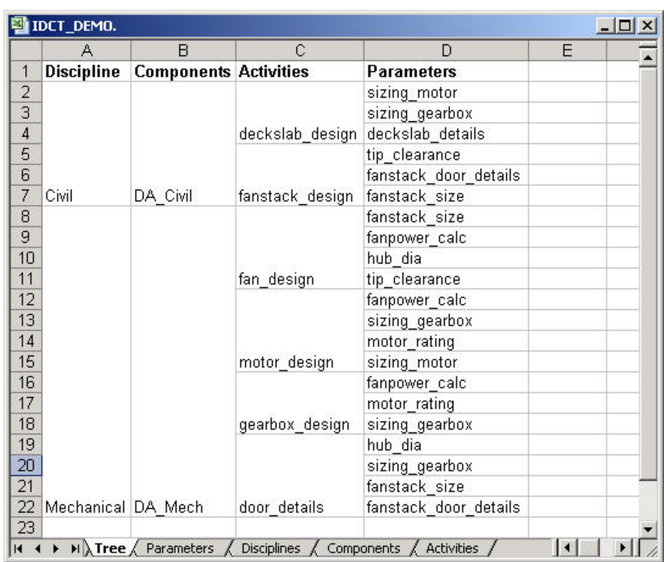


Fig. 12 Output and Input Parameters



IDCT_DEMO.

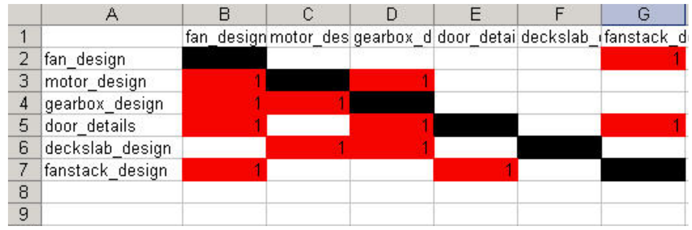
	A	B	C	D	E
1	Discipline	Components	Activities	Parameters	
2				sizing_motor	
3				sizing_gearbox	
4			deckslab_design	deckslab_details	
5				tip_clearance	
6				fanstack_door_details	
7	Civil	DA_Civil	fanstack_design	fanstack_size	
8				fanstack_size	
9				fanpower_calc	
10				hub_dia	
11			fan_design	tip_clearance	
12				fanpower_calc	
13				sizing_gearbox	
14				motor_rating	
15			motor_design	sizing_motor	
16				fanpower_calc	
17				motor_rating	
18			gearbox_design	sizing_gearbox	
19				hub_dia	
20				sizing_gearbox	
21				fanstack_size	
22	Mechanical	DA_Mech	door_details	fanstack_door_details	
23					

Tree / Parameters / Disciplines / Components / Activities

Fig. 13 Tree Formation

V. RESULTS AND DISCUSSIONS

Compared to the conventional approach in the formation of activity DSM with a list of activities and information dependencies among the activities, the proposed method offers potential benefits in defining a complete DSM especially for new DSM users.



	A	B	C	D	E	F	G
1		fan_design	motor_des	gearbox_d	door_detai	deckslab_	fanstack_d
2	fan_design						1
3	motor_design	1		1			
4	gearbox_design	1	1				
5	door_details	1		1			1
6	deckslab_design		1	1			
7	fanstack_design	1			1		
8							
9							

Fig. 14 Formation of Activity DSM

But, significant commitment, time and interaction are required from the expert group in order to form the activity DSM. Such effort and commitment will provide considerable time savings if the data gathered from the expert group for any particular project can be stored as a database for future retrieval.

The above approach was applicable for IDCT type of projects. For complex construction projects, the hierarchical WBS can be altered to suit the respective situations. But, the merging of variable DSMs with activities and parameters to form activity DSM will be applicable for any project scenario.

Further, the proposed approach enables the planners to manage the interactions among the team/ disciplines, components, activities or parameters in a structured manner. It can also be restated that it is possible to form the various types of DSM such as team-based, component, or parameter DSM from the above data collection and activity DSM (this signifies that the interaction among the various elements can also be determined through the above approach).

VI. SUMMARY

Construction projects can be effectively planned and managed with the help of DSM. Even though DSM has been identified as a potential tool for planning and sequencing, its application on construction projects is minimal.

One of the main hurdles identified in the implementation is the formation of activity DSM. The present study offers a structured approach in the formation of activity DSM by merging of the variable DSMs along with the WBS. The prototype tool developed in Excel VBA was helpful in applying the above DSM concepts. The proposed approach was well received by the IDCT group and was found beneficial in forming a activity DSM especially for new DSM users.

This approach can also be used to form the types of DSMs such as team-based, component-based or parameter DSM for effective project planning. Further, the above approach can be extended in the hierarchical approach to suit any project.

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