KNOWLEDGE MANAGEMENT FOR PLANNING CONSTRUCTION PROJECTS USING DEPENDENCY STRUCTURE MATRIX

V. Paul Christopher Charlesraj[1], J. Uma Maheswari[2], Satyanarayana N. Kalidindi[3] and Koshy Varghese[4]

Building Technology and Construction Management Division, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai – 600 036, India

Conventional tools like CPM/PERT can plan the workflow sequences for a project. In order to meet the growing demand for completing the projects quickly, one has to manage the information flow. Dependency Structure Matrix (DSM) is a powerful tool for modelling information flow and planning alternate sequences. An implementation procedure for modelling construction projects using DSM has been elaborated. It includes major phases such as formation of activity DSM, partitioning (re-sequencing the order of execution of activities for a feasible sequence), tearing (choosing a set of dependency relationships for temporary removal by making assumptions), estimation of project duration and rework duration. Effective and efficient planning using DSM requires inputs from domain experts at various phases. A major portion of this is mainly derived from historical information or the personal experience of the experts. This historic information may reside in documents, heads of people, drawings, etc. There is a need to formalise systems that can capture and disseminate the critical information from construction projects for reuse within and across projects. Knowledge Management (KM) can play a major role in meeting this requirement.

Keywords: Construction planning, dependency structure matrix, human resource management, knowledge management, information management.

INTRODUCTION

Conventional tools like CPM/ PERT are not suitable for sequence analysis because they cannot model interdependent activities. Moreover, these tools cannot model information flow. In order to meet the growing demand for completing the projects quickly, one has to manage the information flow. Dependency Structure Matrix (DSM) has been identified as a powerful tool to identify and manage information exchange among activities (Eppinger et al. 2004, Steward 1981). A generic procedure for planning construction projects using DSM, which includes various phases viz. formation of activity DSM, partitioning (re-sequencing the order of execution of activities for a feasible sequence), tearing (choosing a set of dependency relationships for temporary removal by making assumptions), estimation of project duration and

[1] paul@civil.iitm.ernet.in
[2] uma@civil.iitm.ernet.in
[3] satyakn@iitm.ac.in
[4] koshy@iitm.ac.in

Charlesraj, V P C, Maheswari, J U, Kalidindi, S N and Varghese, K (2004) Knowledge management for planning construction projects using dependency structure matrix. *In:* Khosrowshahi, F (Ed.), *20th Annual ARCOM Conference*, 1-3 September 2004, Heriot Watt University. Association of Researchers in Construction Management, Vol. 2, 831-8.

rework duration has been discussed. All the above processes need various inputs at different steps and simultaneously release different outputs.

DSM has been effectively applied in many fields like manufacturing, aerospace, military, etc. However, investigation on the use of DSM in construction projects is marginal even though there is a high potential for application. Among the various limitations, improper information exchange within and across projects is found to be a major bottleneck. The reason behind this is that the executors (managers/ engineers/ designers, etc.) are not aware of the actual process of information flow between various levels and the mode/ type of information exchange and hence fail to manage them effectively. Since the projects are under pressure to complete quickly, 'some' information which may/ may not be relevant to the receiver is generally transferred. Hence, the successful implementation of DSM in any organisation needs the right piece of information at the right time in the right form.

Effective and efficient planning and control using DSM requires inputs from domain experts at various phases. A major portion of this is mainly derived from historical information or the personal experience of the experts. This historic information may reside in files, documents, heads of people, drawings, codebooks, discussions, meetings, videotapes, Internet, mails, etc. There is a need to formalise systems that can capture and disseminate the critical information from construction projects for reuse within and across projects.

Knowledge Management (KM) is one of the recent business management techniques, which is gaining wide acceptance and is being implemented in various sectors to improve organisational competitiveness and performance. Formal implementation of KM concepts, for information capture and dissemination across and within the construction projects is a viable proposition for effective and efficient project planning using DSM.

The objective of this paper is to present the proposed DSM methodology for planning construction projects and to discuss the applicability of KM to capture and reuse project knowledge. Various factors contribute to the planning of construction projects using DSM have been identified. Reuse of captured historical project knowledge with formal KM techniques and technologies will be effective in improved planning using DSM.

DEPENDENCY STRUCUTRE MATRIX

From the survey of tools used to model information flow dependencies and sequences, DSM has proven to be a powerful and flexible tool for sequence planning (Yassine et al. 1999, Kusiak and Wang 1993). A major advantage of the matrix representation over the other tools lies in its compactness, and ability to provide a systematic mapping among the elements that is easy to read regardless of size. It clearly represents where a loop occurs, and procedures to identify and evaluate sequence options. DSM provides a better planning methodology or framework for the managerial decisions.

The basic representation of Activity DSM is a square matrix containing a list of activities in the rows and columns in the same order in a matrix form (Eppinger et al. 2004, Steward 1981). The order of activities in the rows or columns in the matrix indicates the sequence of execution. The relationship between the activities is represented with an 'X' mark in the off-diagonal cells. The diagonal cells generally have no value but the duration for each activity can be included. The activities have to be read along the columns as "gives information to" and along the rows as "needs information from". The marks above the diagonal are called feedback marks and the marks below the diagonal are called feed forward. If any mark lies above the diagonal, it implies that an assumption has to be made to execute the corresponding sequence.

PROPOSED DSM METHODOLOGY

This section presents the solution procedure for planning the activity sequence. The procedure is structured into four phases. The first phase involves in the formation of an activity DSM, while the second phase involves in identifying the cycles and the places for assumptions to be made (partitioning & tearing), the third one helps in estimating the project duration, while the last one in estimating the rework duration. A pictorial representation of the processes involved in various phases while planning the activity sequences is shown in Figure 1.

Phase 1 Formation of Activity DSM

The first phase involves in gathering a lot of inputs starting from collection of project specifications and requirements to the scope of the work. Once this information is gathered, the various disciplines/team members involved in the project discuss and finalise the components along with its function. For each component, the list of activities is defined. After this stage, the information predecessors are decided and the activity DSM is drawn. Here, the above step gives better guidelines in forming activity DSM, especially for new projects. Normally, conventional projects are always unique in nature and hence this phase adds significance in gathering input in a structured manner as presented in Figure 1.

Phase 2 Partitioning & Tearing

The sequence of activities will not be known while gathering the information for the project. Hence, the activity DSM may contain marks above the diagonal, which implies that assumptions have to be made. In order to avoid assumptions, the feedback marks can be brought below the diagonal by rearranging the sequence of activities. If there are loops in the matrix, resequencing the activities cannot result in a lower triangular matrix. Further, the feedback marks have to be brought towards the diagonal as much as possible, because marks far away from the diagonal implies more number of activities have to be reworked in case of a change in assumption. The process of rearranging the order of activities in such a way that there is movement of dependency relationships either below the diagonal or close to the diagonal and the formation of blocks is called *partitioning*.

Once the loops are identified, the activities have to be sequenced within the loops by removing the dependency relationship temporarily (making assumptions) by the process called *Tearing*. Once these assumptions are made for the loops, the sequence of execution can be determined. It can be seen that there can be a number of sequences and tear options available to the planner. Any changes/ refinement in the initial assumptions can cause rework. Hence, additional information on the dependency relationship between the activities within the blocks is essential for choosing specified tear locations.

Since the conventional DSM does not provide adequate information for making tear locations, an advanced version of DSM namely Numerical DSM (NDSM) emerged. It contains numbers between 0-9 in the off-diagonal elements instead of ‘X’ marks.

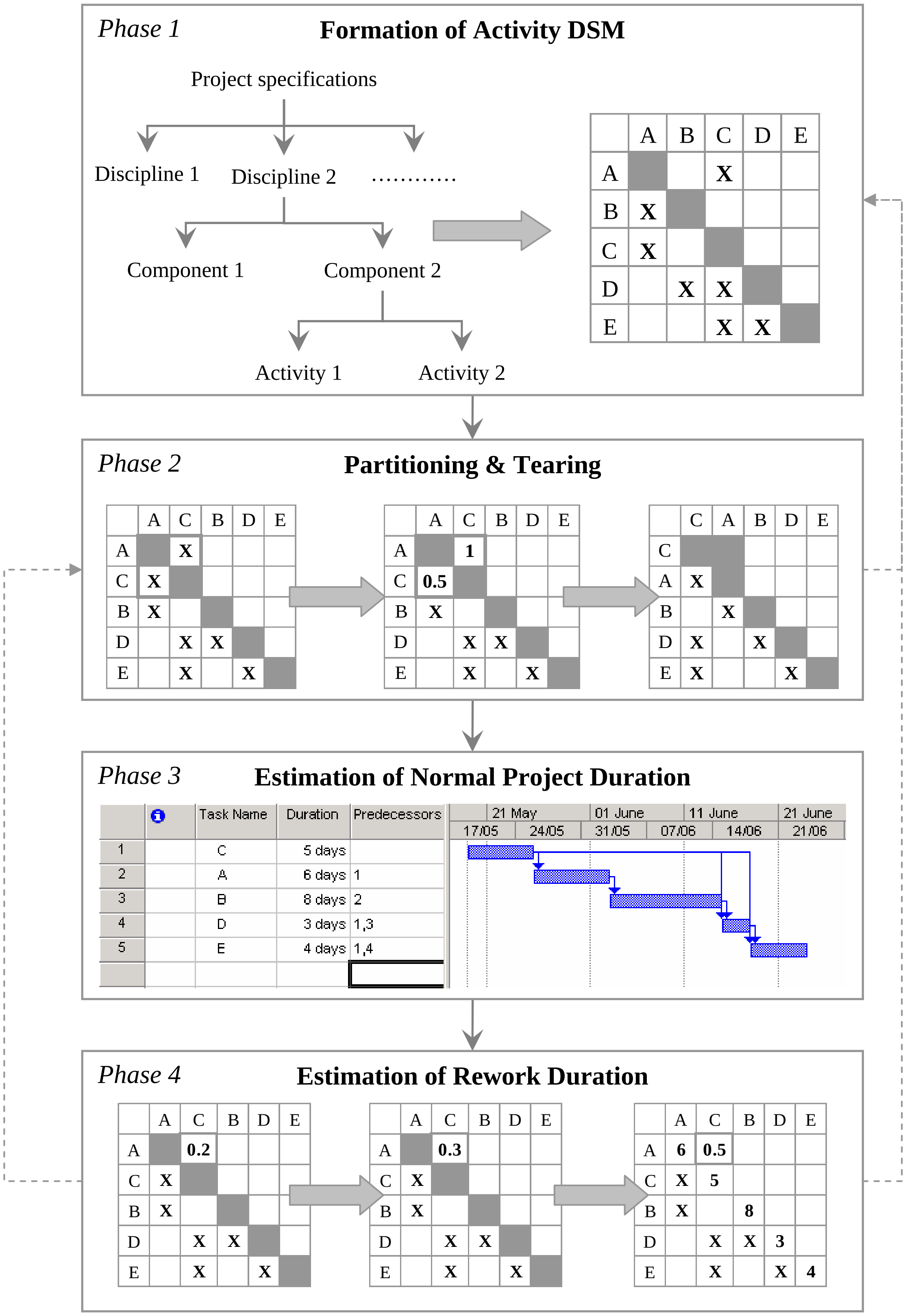

Figure 1 DSM solution methodology

These numbers are obtained qualitatively through interviews, surveys, etc. with the experts in the concerned field. With the help of this information, one can decide the tear locations. The numbers can convey information such as the strength of dependence of a task on specific data, sensitivity, evolution, variability, etc. (Eppinger et al. 2004, Browning 1998). Based on the type and nature of project, the relevant attribute is chosen and the tear locations are determined. *Criticality of assumption* has chosen to decide whether to make assumptions or not. It is represented by a three-point scale as follows: (a) 0 – not critical, and the assumption can be easily made (b) 0.5 – critical, but the information can be assumed (c) 1 – very critical, and the information cannot be assumed. The partitioning and tearing process for the sample is illustrated in Figure 1.

Phase 3 Estimation of Normal Project Duration
Once the activities are resequenced based on the tear locations, the normal project duration (for one cycle) can be determined. The duration for each activity can be given along the diagonal cells. A standard project management tool can be used to find the project duration for the resulting sequence as in the Figure 1, for one cycle.

Phase 4 Estimation of Rework Duration
The above phase does not reveal the amount of repetition of a single or group of activities for the assumptions made. Research groups at MIT applied DSM for modelling and forecasting the impact of assumptions within a set of design activities (Eppinger et al. 2004). However, the impact of the assumptions on the downstream activities has not been explored. Three significant factors, which influences the extent of rework viz. *Information Change Occurrence* (ICO), *Information Change Propagation* (ICP) and *Information Change Consequence* (ICC) were modelled (Maheswari et al. 2004). These factors can be estimated and incorporated in the DSM, so that the managers can take a decision whether to make an assumption or not (Figure 1). This duration gives a realistic estimate of the total project duration including the rework.

Summary
The above section on solution methodology gave a step-by-step process of the raw input data to the processed information (which is split into four phases). The major inputs and the outputs at various phases are shown in the Table 1. Here, the first phase requires maximum input; with manual processing of the information leading to the formation of activity DSM. The inputs for the subsequent phases are very subjective and obtained from the experts or retrieved from historical databases. Hence, the quality/ reliability of the output information is directly dependent on the input information provided. Given the fragmented nature of the construction industry, there is a need for formal systems to capture, store, disseminate, and reuse historical information/expert knowledge. KM can play a major role in the planning and design of such a system. Brief review on KM is presented in the following section and the role of KM in DSM is discussed subsequently.

KNOWLEDGE MANAGEMENT

Of late, in the quest of sustainable competitive advantage, organisations have come to realise that their competitiveness edge is mostly the brainpower or intellectual capital of their employees and management. To be more specific, an organisation's competitive advantage depends on *what it knows – how it uses* what it knows – and *how fast* it can know something new. In order to stay ahead of the pack, organisations must leverage their knowledge internally and externally to survive. KM helps an organisation to gain insight and understanding from its own experience. Specific KM activities help focus the organisation on acquiring, storing and utilising knowledge for problem solving, dynamic learning, strategic planning and decision making. It also protects intellectual assets from decay, adds to organisation intelligence and provides increased flexibility.

Table 1 Input and output for DSM-based planning

Input	Output
Phase 1 Formation of Activity DSM	
1. Project Requirements 2. Disciplines/ teams involved 3. Components considered 4. Scope of work 5. Number of activities 6. Activity name/ ID 7. Dependency relationship among the activities	• Activity DSM
Phase 2 Partitioning & Tearing	
1. Identification of shorter loops within the blocks 2. *Criticality of assumption* for each relationship in the identified loop	• Partitioned DSM • Tear locations • Sequence of execution
Phase 3 Estimation of Normal Project Duration	
1. Deterministic duration for each activity	• Project duration (for one iteration)
Phase 4 Estimation of Rework Duration	
1. *Information Change Occurrence* (ICO) for each assumption 2. *Information Change Propagation* (ICP) for the downstream activities	• Rework duration calculated with the help of ICO & ICP

Why KM?

The emergence of KM may be explained by the confluence and natural evolution of several factors. KM is a necessity, driven by the market forces of competition, market place demands, new operating and management practices, and the availability of KM approaches and Information & Communication Technologies (ICT). Some of the specific needs for KM are:

- Globalisation of the economy, which is putting terrific pressure on organisations for increased adaptability, innovation, and process speed.
- The awareness of the value of specialised knowledge, as embedded in organisational processes and routines, in coping with above pressures.
- The awareness of knowledge as a distinct factor of production and its role in the growing book to market ratios within knowledge-based industries.
- Organisations are becoming knowledge intensive, not capital intensive.
- KM lets you lead change so that change does not lead you.

- Knowledge can only survive.
- Knowledge can drive support.
- Tacit knowledge is mobile.

What is KM?
KM deals with the conceptualisation, review, consolidation, and action phases of creating, securing, combining, coordinating, retrieving, and using *organisational knowledge*. Organisational knowledge can be defined as the processed information embedded in organisational routines and processes that enable action. It is also knowledge captured by the organisation's systems, processes, products, rules, and culture. The following definition is used for KM in this research:

> *KM can be defined as the systematic and explicit management of knowledge-related activities involving knowledge-workers in an organisation to improve organisational knowledge-related efficiency and effectiveness, thereby to achieve specified organisational goals and objectives.*

How KM can be implemented?
There are several tools (techniques and technologies) available and are practiced to implement KM in construction organisations (Egbu et al. 2003). Some of the widely used techniques are: Communities of Practice (CoP), Brainstorming, Face-to-face interaction, Post Project Reviews, Mentoring, and Job Observation/Rotation Systems. The following technologies are commonly used for KM in organisations: Intranet, Extranet, Groupware, Internet, Data and Text Mining, Document Management Systems, Knowledge bases, and Taxanomy/Ontologies.
Selection of appropriate techniques and technologies is very important for effective and efficient KM in construction organisations and it is governed by many factors such as knowledge dimension and KM sub processes of focus. The critical knowledge dimensions are: (i) knowledge conversion types (tacit-explicit), (ii) knowledge ownership forms (personal-shared) and (iii) knowledge transfer domains (internal-external) (Al-Ghassani 2003). Various KM sub processes as identified by (Kamara et al. 2002) are: (a) Locating and Accessing, (b) Capturing and Storing, (c) Representing, (d) Sharing, and (e) Creating knowledge.

ROLE OF KM IN DSM

Various KM techniques and technologies will be helpful in managing the information required for DSM implementation. Information from the previous projects becomes vital while planning similar kind of construction projects. So, capturing the project knowledge from similar project during their course of execution itself is necessary. Lessons Learned Systems (LLS) and Post Project Reviews (PPR) are the suggested techniques for capturing the project knowledge during and after the project execution. With the advent of advanced ICT, it is easier to capture and disseminate the project knowledge from/to projects which are geographically widespread (Charlesraj 2003). Transferring/disseminating this wealth of knowledge within and across the projects/organisations can be much more effective if the Internet, Intranet, Extranet, and Groupware technologies as well as the techniques like Communities of Practice (CoP), Mentoring, and Training are implemented with specific objectives in mind. The project planners always look for information from various sources. The sources may vary from books-websites-experts and so on. So there should be an effective mechanism to locate/identify the desired information as quickly as possible and also the authenticity and accuracy of information should be ensured. Knowledge Maps, Expert Directories, and Corporate Yellow Pages are some of the techniques and technologies like Data/text mining can be used to search for useful information. Brainstorming sessions will be quite beneficial during the initial phases where more meetings among the teams are expected to finalise the specifications and the work breakdown structure. With the higher level of knowledge representation using Taxonomies and Ontologies, access to specific information in a faster pace can be accomplished. So, if appropriate KM techniques and technologies are employed in construction organisations, it would facilitate better performance of DSM-based planning.

SUMMARY & CONCLUSIONS

DSM is useful for planning the activity sequences and managing information exchanges among activities. The DSM-based solution procedure for project planning involving the formation of activity DSM, partitioning, tearing, estimation of project duration and the rework duration has been discussed. The critical inputs viz. *Criticality of assumption, Information Change Occurrence* and *Information Change Propagation* for the estimation of rework duration of a project using DSM has been identified. Further, these inputs require expert opinion and historical information at various stages. Access to and search for the historical information or experts is not that easy in the construction domain owing to its fragmented nature. Hence, the applicability of KM concepts to achieve the objective of locating/searching, capturing, sharing and reusing project knowledge has been discussed. In view of the fact that research in construction KM is in its formative years, there is a significant need to study the role of KM in project planning using DSM. Further investigation can be made on the identification of critical success factors of DSM-based planning and the exploration of applicable KM techniques and technologies to manage them.

REFERENCES

Al-Ghassani, A M (2003) *Improving the structural design process: a knowledge management approach*, Unpublished PhD Thesis, Department of Civil and Building Engineering, Loughborough University, UK.

Browning, T R (1998) Use of Dependency Structure Matrices for product development cycle time reduction, *Proceedings of the 5th ISPE International Conference on Concurrent Engineering: Research and Applications*, 15-17 July 1998, Tokyo, Japan.

Charlesraj, V P C and Kalidindi, S N (2003) CLLIS - A lessons learned system for knowledge management in construction organisations, *Proceedings of the Second International Conference on Construction in the 21st Century (CITC-II)*, 10-12 December 2003, Hong Kong, 414-419.

Egbu, C O, Kurul, E, Quintas, P, Hutchinson, V, Anumba, C, Ruikar, K, and Al-Ghassani, A (2003) Techniques and technologies for knowledge management, *Final Report - Work Package 3*, Project Title: KM for Sustainable Construction Competitiveness.

Eppinger, S D, Whitney, D E, Yassine, A A and Roemer, T (2004) The MIT Design Structure Matrix - DSM - Home Page, < *http://www.dsmweb.org*>, visited on 15 May 2004.

Kamara, J M , Anumba, C J and Carrillo, P M (2002) A CLEVER approach to selecting a knowledge management strategy, *International Journal of Project Management*, **20**(3), 205-211.

Kusiak, A and Wang, J (1993) Efficient organising of design activities, *International Journal of Production Research,* **31**, 753 – 769.

Maheswari, J U, Varghese, K, Sridharan, T, Rao, B S, Bhaskaran, S and Ramasubramanian, S (2004) Managing Rework in Concurrent Construction Projects using Advanced Dependency Structure Matrix, *Proceedings of International Symposium of CIB – W92 on Procurement Systems,* 7-10 January 2004, Indian Institute of Technology Madras, Chennai, India, 150-161.

Steward, D V (1981) The Design Structure System: A Method for Managing the Design of Complex Systems, *IEEE Transactions on Engineering Management,* **EM-28**(3), 71-74.

Yassine, A, Falkenburg, D and Chelst, K (1999) Engineering design management: An information structure approach, *International Journal of Production Research,* **37**(13), 2957-2975.