Design Structure Matrix: An Approach to Reduce Iteration and Acquire Optimal Sequence in Construction Design and Development Projects

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Abstract

Design is an iterative, generative, and multidisciplinary process by its nature. Iteration is frequent in most of the engineering design and development projects including construction. Design iterations cause rework, and extra efforts are required to get the optimal sequence and to manage the projects. Contrary to simple design, isolation of the generative iterations in complex design systems is very difficult, but reduction in overall iterations is possible. Design depends upon the information flow within domain and also among various design disciplines and organizations. Therefore, it is suggested that managers should be aware about the crucial iterations causing rework and optimal sequence as well. In this way, managers can handle design parameters related to such iterations proactively. Numbers of techniques are available to reduce iterations for various kinds of engineering designs. In this paper, parameter based Design Structure Matrix (DSM) is chosen. To create this DSM, a survey was performed and then partitioned using a model. This paper provides an easy approach to those companies involved in or intend to be involved in "design and build projects."

Keywords: **Design management, Construction, Information management, Model, Project management**

1. Introduction

Iterations are unavoidable in design causing delays and chaos. On the other hand it is obligatory to produce design values. However, not all iterations generate value (Ballard 2000). But for efficient management we have to get rid of iterations that are not generating values or, at least have to reduce such iterations. Besides the tremendous magnitude of information involve, the complexity with which this information flows contributes considerably to the difficulty of design (Gebala and Eppinger 1991). It is also a fact that construction design projects involve more design changes. Out of several techniques available, Design Structure Matrix (DSM) method is chosen as it can efficiently eliminate or reduce iterative loops by re-sequence design parameters/tasks. In addition to this, it is also helpful for finding an optimal sequence. The design is always an easy prey for internal and external uncertainties. The application of matrices in design management of construction projects is not very common but for simulation or modeling it is widely acceptable. This paper addresses the re-sequence of the design parameters of various Design subsystems (DS) using DSM based analysis model. The purpose for putting emphasis on this approach and model is because the construction companies are now more involved in design and build based project to attain contractual integration.

2. Interrelationship Representation

In complex and large projects, the representation of interaction among various DS parameters is a difficult task. But DSM provides an easy and compact method to allocate and understand interaction. In design systems analysis, it is also called precedence matrix. A precedence matrix is a square matrix with as many rows and as many columns as there are vertices in the graph (Steward 1981). DSM is a tool to eliminate or minimize iterative loops by resequence task.

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Any design system is a result of interaction of its various subsystems' parameters or components. Relationship among these can be characterized by three fundamental building blocks; Parallel (independent), sequential (dependent), and coupled (interdependent), as shown in Figure 1.

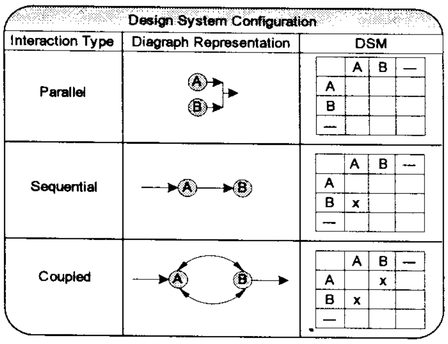

Figure 1. Interaction Types & Representation in Design

3. DSM Concept & Configuration

DSM configuration is as following: place down the design parameters/ activities names on the left side of matrix as row headings and across the top of matrix as column headings in the same order (square matrix) as shown in Figure 2.

The dependency of one parameter to other is represented by "x" or "1" marks in the off-diagonal cells. Otherwise it is left empty or assigned "0" mark. Usually the diagonal elements of DSM left empty or blackened-out. But for DSM analysis, where the binary numbers (0 and 1 only) involve, it should be zero. The dependency has to be read along the rows as "information required from" and along the columns as "information provided to." DSM is a method to eliminate or minimize iterative loops by re-sequence of design parameters involved. Iterative loops can be identified by "x or 1" mark above the diagonal line of DSM. It depicts that information is required from downstream (later listed) parameter, and is called feedback mark. Similarly, such mark below the diagonal depicts that information can be transferred later, and is called feedforward mark. The main objective of DSM method is to keep it in lower triangular form to obtain a sequence where each one can be executed only after it receives all information from its predecessors (Eppinger et al. 1993). But it may happen only in simple design project cases. Therefore, for large complex design projects it is suggested to keep feedback marks to a minimum and close to the diagonal line in order to get optimal sequence and crucial iterations.

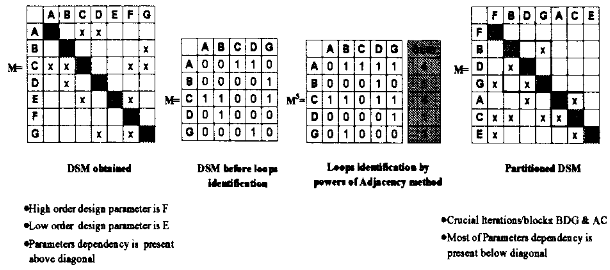

Figure 2. DSM Partitioning by Powers of Adjacency Method

4. DSM Analysis

DSM analysis implies the reordering of the given sequence resulting in optimal sequence including the crucial design parameters which require rework.

4.1 Partitioning Algorithm

It is the process to reorder rows and columns of DSM in order to get a new sequence having no or least feedback marks. The partitioning algorithm is stated as following:

1. Identify the design parameters that require no information, which can be noted by observing empty rows in DSM. Separate such parameters from DSM (i.e. from rows and columns both) as high order design parameter in sequence. If more empty rows are found after separating then repeat this process until a DSM, having no empty row, is achieved.
2. Identify the design parameters that provide no information, which can be noted by observing empty columns in DSM. Separate such parameters from DSM (i.e. from columns and rows both) as low order design parameter in sequence. If more empty columns are found after separating then repeat this process until a DSM, having no empty column, is achieved.
3. If all design parameters have separated, then DSM is already partitioned after step 2. Otherwise, after completing step 1 and 2 or in cases where DSM has no empty rows and column then identify the loops causing rework.

4.2.1 Identification of loops by Powers of adjacency method

Loops in DSM can be identified using path searching method, powers of adjacency method, and reachability matrix method etc. In the proposed model the powers of adjacency method is used. This method involves taking the powers of DSM under consideration and then priority in the order is given to the parameters having least row sum. Take the powers of DSM until the matrix does not change or until the power matrix equal or exceeds the order of matrix (Steward 1962). In order to avoid the complexity of calculation Authors proposed to take the powers of DSM equal to the order of square matrix. During the process of taking powers of DSM the assigned dependency is also disturbed. The powers of adjacency method consists of the following steps:

4. After separating high and low order parameters from the DSM obtained, make adjacency matrix by indicating the dependency mark '1' and remaining cells including off-diagonal cells by assigning mark '0.'

5. Take power of matrix (equal to order) by applying condition "value >1=1" during multiplication.

6. Sum each row (design parameter) separately and arrange in increasing order.

7. Finally, to get the partitioned DSM, place design parameters related to loops between the high and low order design parameters obtained. Assign dependency to all design parameters as it was present in the DSM obtained before analysis.

In partitioned DSM, dependency of all parameters remains same, only the sequence changes. Figure 2 depicts the DSM Partitioning algorithm.

5. Proposed Model

5.1 Research Methodology and Model Algorithm

The research methodology involves the survey from engineers/managers to make DSM and then input into the model engine to obtain the results. The compilation of results provides a required Partitioned DSM. Almost 20 surveys have been performed, which include building, sewer, bridge, and harbor design projects.

5.2 Implementation Example

Although DSM has a wide range of applications, but for construction point of view the DSM methodology is not very common. The construction design projects like harbor and roadway are frequently subjected to sudden changes in design, even during the construction phase. Hence, the harbor design project has been chosen for implementation example. On the basis of survey Table 1.

Table 1. Survey Results of Harbor Design Project

Code	Design Parameter	Required Design Parameter	Design Subsystem
1	Decision of vessel types		Design condition (D)
2	Wind pressure		
3	Wave		
4	Wave force		
5	Tides		
6	Types of breakwater structure	2,3,4,5	Counter facilities design (C)
7	Breakwater section decision	6,8,9,10	
8	Breakwater exterior force calculation	2,3,4,5	
9	Breakwater stability calculation	2,3,4,5,7	
10	Breakwater member design	8	
11	Revetment design	2,3,4,5	
12	Gravity quay wall design	1,2,3,4,5	Mooring facility design (M)
13	Pier quay wall design	1,2,3,4,5	
14	Tie rod sheet pile quay wall design	1,2,3,4,5	
15	Lathe sheet pile quay wall design	1,2,3,4,5	
16	Cell type sheet pile quay wall design	1,2,3,4,5	
17	Steel sheet pile design	1,2,3,4,5	
18	Floating pier design	1,2,3,4,5	
19	Dolphin design	1,2,3,4,5	
20	Ocean lane	1	water facilities design (W)
21	Mooring basin	1	
22	Turning basin	1	
23	Small diurnal range	1	
24	Dredging soil calculation		Dredging and reclamation (R)
25	Dredger and dredging methods	24	
26	Dredging capacity	24,25	
27	Disposal place of dredged soil	24,25,26	
28	Reclamation method of reclaimed soil		
29	Marina water facilities	1,2,3,4,5	Marina design (A)
30	Marina counter facilities	1,2,3,4,5	
31	Marina mooring facilities	1,2,3,4,5	
32	Marina safety facilities	1,2,3,4,5	
33	Navigation system design and analysis		Aids to navigation facility design (N)
34	Light house and light pole		
35	Pilotage and leading lights		
36	Beacon lighting buoy and buoy		
37	Bridge marks on sea		

the DSM has obtained and loaded to model engine. The complete operation to use DSM interface is shown in Figure 3. The Partitioned DSM of harbor design project offered the optimal sequence along with one crucial iteration of design parameters.

6. Conclusion

The significance of information flow in design is widely acceptable but the multidisciplinary nature of design always causes hindrance in it due to iterations. The emerging corporate trend in construction is also causing multifarious problems regarding responsibility measures. The optimal sequence and lessen the rework have been challenging tasks for managers. The DSM has the capability to represent the information requirements of complex design projects and is a tool to get crucial iterations and optimal sequence. Its combination with Critical Path Method (CPM) and use of numeric DSM may also lead to technical and managerial benefits. In the proposed model, compilation of results causes some time delays to the user but the model is an effective tool to obtain required results. The proposed model not only facilitates the managers to manage the iterations proactively but also illustrates to software systems for design management. The survey data can also be utilized as regional trend about design management.

Reference

1. Ballard, G. (2000). "Positive vs. negative iterations in design" Proceedings Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK, July 17-19.
2. Eppinger, S.D., Whitney, D.E., Smith, R. P., and Gebala, D.A. (1993). "A model-based method for organizing tasks in product development." WP# 3569-93-MS.
3. Gebala, D.A., and Eppinger, S. D. (1991). "Methods for analyzing design procedures." DE- Vol. 31, Design theory and Methodology ASME.
4. Steward, D.V. (1981). "System analysis and management: structure, strategy, and design." Petrocelli Books, New York.
5. Steward, D.V. (1962). "On an approach to technique for the analysis of the structure of large systems of equations." SIAM Review, Vol. 4 No.4, pp.321-342.

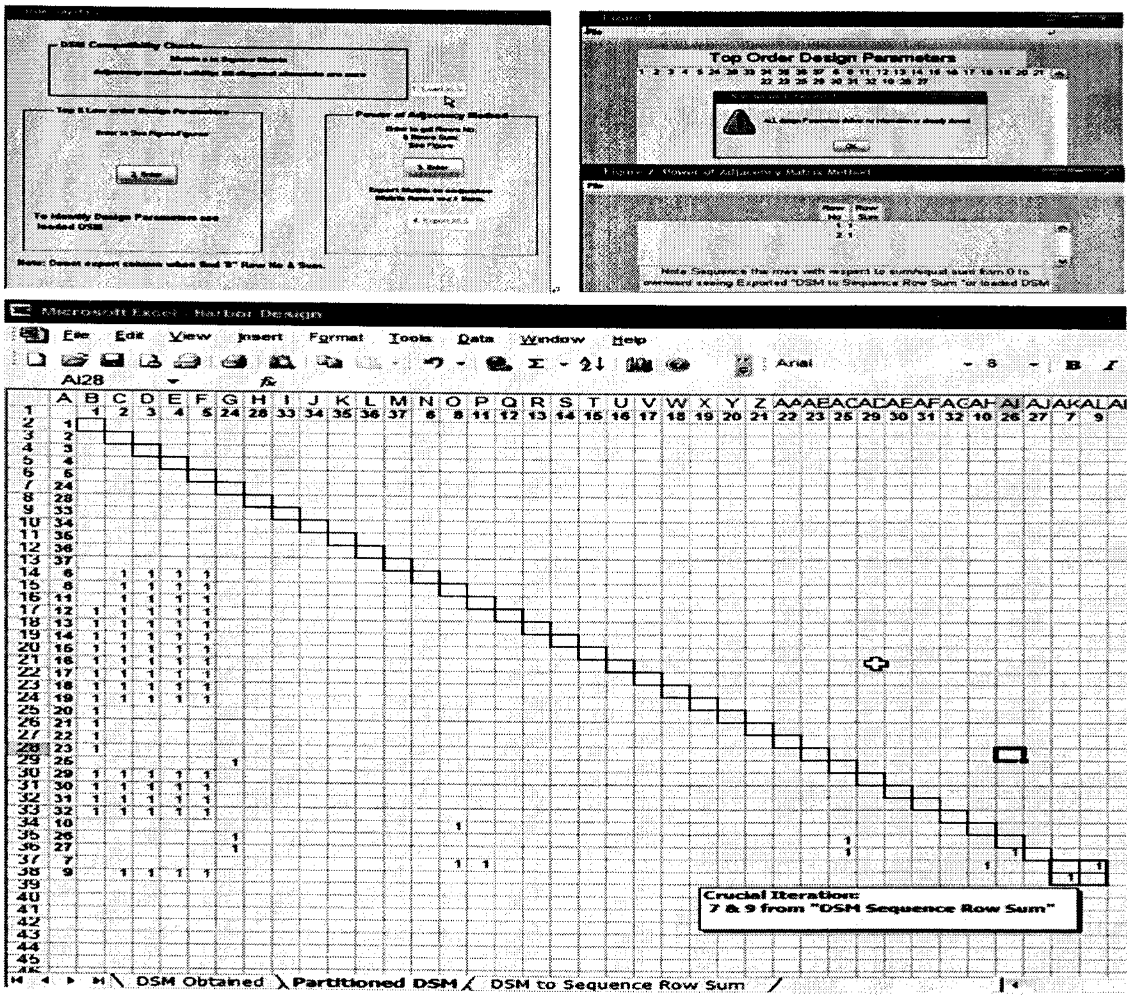

Figure 3. DSM User Interface