Possibilities of the design structure matrix for planning and system analysis of complex engineering systems

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Abstract. The concept of complex engineering objects is closely connected with approaches, methods, management tools for such objects. Modern approaches are based on project management, i.e. on the management of a unique, temporary, multidisciplinary and organized effort aimed at obtaining a consistent final result within predetermined requirements and constraints. The article considers one of the promising methods for building and analyzing the dependency structure of a project, allowing the user to model, visualize and analyze dependencies between objects of any system and receive suggestions for improving or synthesizing the system. Such a system can be, for example, the architecture of a product or an engineering design process, as well as, the organization of an enterprise or a market formed as a complex system and often requires a closer study of its structure. The article describes the significance of the method, its advantages and disadvantages. Examples of the method implementation in design and construction, as well as in IT.
Keywords: project management, human capital management, DSM, resource planning, agile, hybrid planning

1 Introduction

The concept of complex engineering objects is closely connected with approaches, methods, management tools for such objects. Modern approaches are based on project management, i.e. on the management of a unique, temporary, multidisciplinary and organized effort aimed at obtaining a consistent end result within the framework of predetermined requirements and restrictions [1, p. 40]. Article objective is to review the Design Structure Matrix (DSM) as a method for managing functional areas in the design and construction of complex engineering objects.

DSM has been widely used and put into practice in the United States and European countries since 2007. The term DSM was originally introduced in the 1960s by Don

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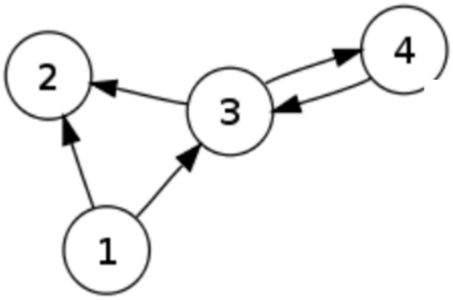
Steward [2, p. 71-74]. From a mathematical point of view, the DSM method is not absolutely new and is represented in the classical graph theory by the concept of «adjacency matrix» [3, p. 8] (Figure 1). And therefore, for such a graph, well-known operations are



$$\mathbf{A} = \begin{pmatrix} 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

performed to check reachability, find the shortest path, etc.

Fig. 1. Adjacency Matrix A for graph G (Compiled by the authors).

Each project consists of elements set. Each functional area of project management is characterized by its own elements set and their characteristics. For example, time management is characterized mainly by 3 parameters: the name of the work, their interconnection, as well as duration of each of them. Communication management consists of the team names, people, and the relationship between them. Also, the project itself, for example, a complex engineering object, has its own structure of elements, subsystems. The matrix method of a dependency structure constructing is an alternative way of modeling and analyzing the system interconnections compared to the classical one (numerical, tabular, network graph, etc.).

2 Materials and Methods

2.1 Object architecture construction

Lets take the object, the system consists of a finite number of 10 elements. Moreover, the relationships between the elements are built in a known way. Then the DSM will look like this (Figure 2).

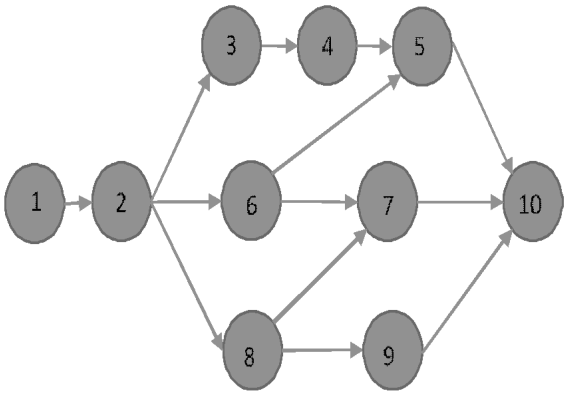


Fig. 2. Relationship between elements in the study object and the corresponding DSM (Compiled by the authors).

Such a matrix has the main characteristic - binary (i.e., a matrix filled with only zeros and ones).

Simple binary matrices are useful for modelling large complex objects, because matrix representation of relationships has the advantage of compactness, visibility and the ability of structural display between the elements of the system, which allows a detailed analysis of a limited set of elements in the context of the overall object structure. The values along the diagonal of the matrix indicate that these elements are included in the object. The values at the top of the matrix represent direct relationships. The values at the bottom of the matrix represent feedbacks.

The next type of matrix, shown in Figure 3, has elements with values from zero to one.

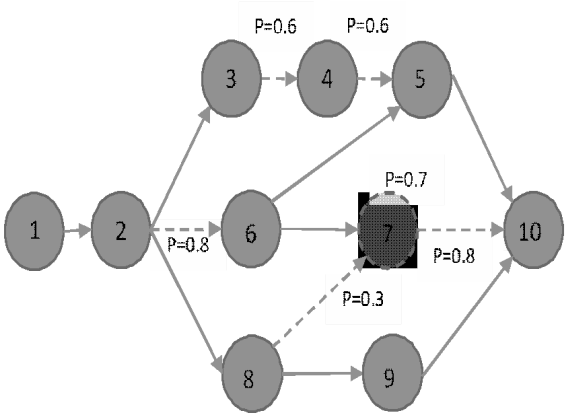


Fig. 3. Defined relationships between elements in the object of study and the corresponding DSM (Compiled by the authors).

P is relationship definition or object element. For example, *P* might represent the probability of a task being included in a project, as well as the relationship between two tasks. This type of matrix allows you to carry out the calculations necessary for the analysis, for example, project feasibility, project completion probability, as well as to carry out some operations to optimize the object.

Also, a less common type of matrix contains values from zero to n, which can mean, for example, the duration or cost of completing a task. However, for useful practical calculations, there is another way to represent matrices based on domains, discussed later in this paper.

Let us observe the general possibilities, as well as the matrix method advantages for constructing the dependency structure.

- The ability to take into account feedback, which is not feasible using the classic Gantt chart.

- Convenient, compact sequences (works) volumetric number visualization, as well as the ability to split matrices into levels (similar to the classic planning schedule)

- Performing Work Clustering (search for groups of elements that are largely interconnected, but have little to do with the rest of the system on any basis), Figure 4.

X	1	2	3	4	5	6	7	8	9	10
1	1	1	0	0	0	0	0	0	0	0
2	0	1	1	0	0	0	0	0	0	0
3	0	1	1	1	0	0	0	0	0	0
4	0	1	0	1	1	1	1	0	0	0
5	0	0	0	0	1	0	0	0	0	0
6	0	0	0	0	1	1	1	0	0	0
7	0	0	0	0	1	1	1	0	0	0
8	0	0	0	0	0	0	1	1	1	0
9	0	0	0	0	0	0	0	0	1	1
10	0	0	0	0	0	0	0	1	0	1

Fig. 4. Task clustering example (Compiled by the authors).

- Performing Sequencing task (changing the order matrix rows and columns so that the new matrix architecture does not contain any feedback labels, thereby converting the DSM to an upper triangular shape). This operation is a powerful tool for reengineering complex systems.

- Performing a «Tearing a DSM» or break to remove feedback marks. Identifying the «gaps» that lead to the upper triangular matrix means that we have identified a set of assumptions that need to be made in order to start iterations of the design process when related tasks are encountered in the process. Once these assumptions are made, no additional estimates need to be made.

- Performing «Banding a DSM» or grouping to find the critical path.

- The use of advanced numerical methods to develop the ability to solve problems of planning and optimization schedules for the design and construction of complex engineering facilities.

All listed possibilities of the presented operations serve as a powerful tool for analysis, optimization, search for optimal solutions, and the matrix method is used as a support system for managerial decisions of decision makers.

2.2 Matrix method of flexible project planning

The matrix method was mainly used for planning and graphical representation of production development projects along with network planning methods.

Agile, flexible and extreme project management methods are becoming more and more popular among practitioners, especially in the sectors of information technology, research and development [4, p. 2]. Table 1 compares the various traditional and hybrid approaches in terms of project scheduling.

Table 1. Various traditional and flexible approaches comparison.

Approaches	Functions		
	Project structure	New tasks	Multimodes
Traditional (TPMa)	Fixed	Not allowed	Handled
Agile (APMa)	Flexible	Not allowed	Not handled
Extreme (XPMa)	Flexible	Allowed	Not handled
Hybrid (HPMa)	Flexible	Allowed	Handled

A flexible project structure allows you to reorganize the original version of the project, taking into account the priorities of the tasks, as well as customer requirements. The fixed project structure cannot be changed. This is characteristic only of the traditional planning approach. Allowing the inclusion of new tasks in the working process on a project indicates the possibility of changing the structure of the project, for example, at the end of a subproject (sprint), if such an action is not allowed, tasks are added in the next subproject. The last comparison column is responsible for handling multiple termination modes.

Research work of the Hungarian scientist Z.T. Kostyan [4, 5] deserves special attention in view of his consideration of wider possibilities for applying the matrix method. In his articles, the mentioned author introduces the definition of "Project Expert Matrix (PEM)", which allows you to set the probability values, relative importance and priority level for tasks, as well as set uncertain relationships between them. This makes it possible to model uncertain completion tasks and flexible dependencies in the project, which makes it possible to move away from the classic (traditional) planning approach and move towards flexible, for example, agile projects. Such a transition allows not only to reduce risks compared to traditional approaches, but also allows project managers to implement the optimization of the project schedule to achieve a specific goal under given constraints.

As part of the project planning, Z.T. Kostyan proposes to represent time, cost and resource costs by areas (submatrices) and their relationship to tasks and to each other using a domain mapping matrix. Since traditional DSMs focus on one area, their analysis gives solutions that are considered optimal in terms of that particular area. Therefore, the Domain Mapping Matrix (DMM) provides means to represent interactions and relationships between domains (eg human resource tasks).

Figure 5 shows the MFPP software processing pipeline [5, p. 4].

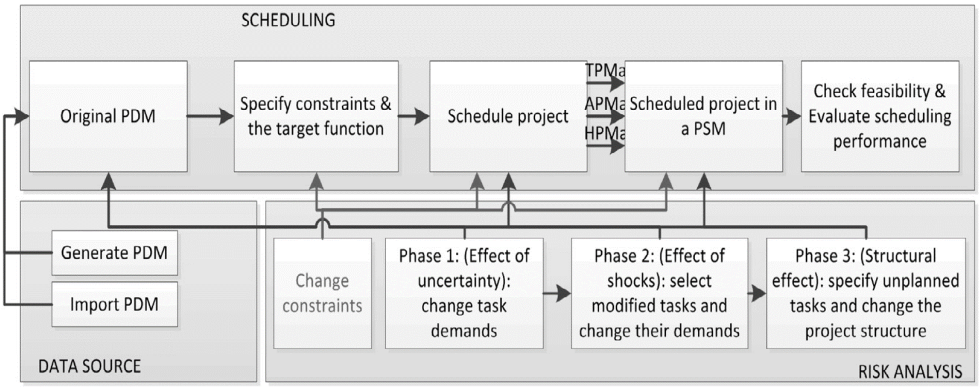


Fig. 5. MFPP Processing Pipeline *[5, p. 4]*.

During the first step, a Project Domain Matrix (PDM) is created or imported from the project database. The logical area of the PDM is an upper triangular matrix. At the second

stage (block 2), restrictions and the objective function are set. The third step is the planning stage, which determines the project plan, given by the PDM using one of three approaches - traditional, agile or hybrid. The last stage (fourth block) in terms of planning is the feasibility check and evaluation of the effectiveness of planning. If there is no risk analysis (fifth stage), the creation of the project plan is completed and the program ends.

The outputs are solutions to project structure matrices that contain logical plans, task requirements, and scheduled task runs. Changing restrictions and changing requirements are separated. All risks are optional. Both the original project plan and constraints can be changed during the risk analysis process. In addition, requirements and constraints are subject to be changed throughout the planning process, and they may change planned projects modelled by project structure matrices.

2.3 DSM in IT

In the course of the ongoing development of information technology and digitalization, IT can be identified as one of the largest areas of the DSM application, together with the field of design and construction. The matrix approach, the underlying graph theory and the binarity of elements (in the classical version) allow a detailed analysis of a certain set of elements in the context of the overall project structure, winning in compactness, simplicity of visual representation and the ability to display the system structure in a format convenient for analysis.

ProjectDSM is one of the options for a software solution of project management based on the matrix method, the application of which is not limited to one area and is suitable for solving project planning problems in both small and large research organizations and commercial enterprises in manufacturing industries (automotive, defense, polymers, materials), as well as industry-based technologies (robotics, biomedical devices, ecology). This tool does not have special requirements for user competencies, it has an intuitive interface.

ProjectDSM can be used for both system architecture and task-based projects using user-configurable descriptors and labels. Project assumptions made while optimizing the project sequence of elements are recorded for targeted verification of assumptions, risk management, and inclusion in the final project schedule. Software output (DSM, dependency map, Gantt chart) is automatically generated and can be used to clearly communicate with project stakeholders [6].

Another example of the DSM method using in the IT field is NDepend, a .NET tool for static code analysis. This tool allows developers, architects and managers to make intelligent decisions on projects. DSM is less clear than a graph (the classic way to represent dependencies in a project), but can be very effective for representing a graph that is larger than a hundred elements. The advantage of DSM is the ability to identify a code structure template at a glance. NDepend DSM comes with a lot of options, namely: it has a lot of possibilities for learning dependencies; work with both square symmetrical DSM and rectangular non-symmetrical DSM. The indirect use option is supported. Lines can contain elements of third-party code [7].

As part of assessing the software development quality and optimizing and improving the program code, you can consider the tools Lattix (Parasoft C / C ++ package) and Designite (for C #).

Parasoft helps prioritize regression testing using Lattix impact analysis to run unit and integration tests that are most likely to be affected first [8]. Designite is a software development quality assessment tool. It analyzes C# code and identifies software quality

issues. In particular, it discovers a full set of architecture, design and implementation options and provides mechanisms such as detailed metric analysis, dependency structure matrix, trend analysis [9].

2.4 DSM in design and construction

Good management requires reliable information for the right people at the right time, and the lack of it leads to team turbulence, demotivation, rework, inefficiency, uncertainty about progress, and too frequent delays in delivering the right information [10]. Adept Management is a specialized consulting company providing clients with project planning and management support, delivering work programs and complex capital projects. The proposed software "Flow" is a management decision support system based on the DSM method.

Flow software allows complex projects to be defined in terms of process steps and communication. It allows you to establish process sequences using DSM that define key decision points in any process and iteration area. Strategies for decomposing or "breaking" iterations can be identified and written into the software. Gantt chart process views can be created using tools such as Oracle Primavera P6. The software allows continuous monitoring and control of the process through predictive scheduling, progress tracking, constraint analysis, and problem/action tracking.

The proposed technical solution is widely used in the field of architecture, design and construction, defense, aerospace and manufacturing sectors. It is also used in general business management, another complex, iterative and information-driven process.

2.5 Human resource management using a matrix approach

People are the most important resource of any campaign. They are directly involved in the generation of ideas and scientific discoveries, the creation of new products, the introduction of new technologies, quality control of the work performed, and technical and other types of support for the results of intellectual or technological activities.

The human resource, its possibilities and initiative are limitless. Competent human capital management allows organizations to win competition on the industry market, take a leading position, and increase the capitalization of the company.

Important aspects of effective cooperation are the competent formation of a team, taking into account the relevant competencies of specialists. Collaboration between departments is a key factor in effective product development [11, p. 5].

To manage human capital using a matrix approach, it is planned to expand the DSM to domain mapping matrices (DMM). This matrix is formed to obtain groups ("clusters") of components and properties that are very similar within each cluster [12]. Then the appropriate personnel are assigned to the clusters, and the people included in the cluster form a team. Figure 6 is a process example showing the person responsible for each task. The matrix on the left shows how these people can be mapped to task.

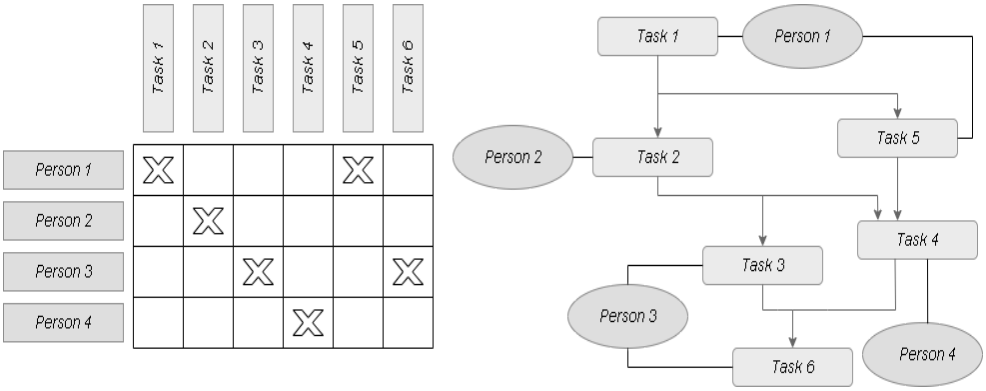


Fig. 6. Human resource management technology using domain mapping matrix (DMM) *[12]*.

When managing multiple functional areas in a system where the number of elements in the matrix exceeds thousands, it is advisable to move from DSM and DMM to a matrix of multiple domains (MDM). MDM allows you to analyze the structure of the system in several domains, combining each individual analysis into one DSM, which simultaneously represents several domains. Figure 7 shows the concept of MDM. It shows that the MDM is a DSM with more detailed DSMs along the diagonal and DMMs off the diagonal [13].

The right side of Figure 7 shows human resources structure working on the project. Because the design team is different from the actual organizational structure, both views are integrated into MDM, which now represents the entire system.

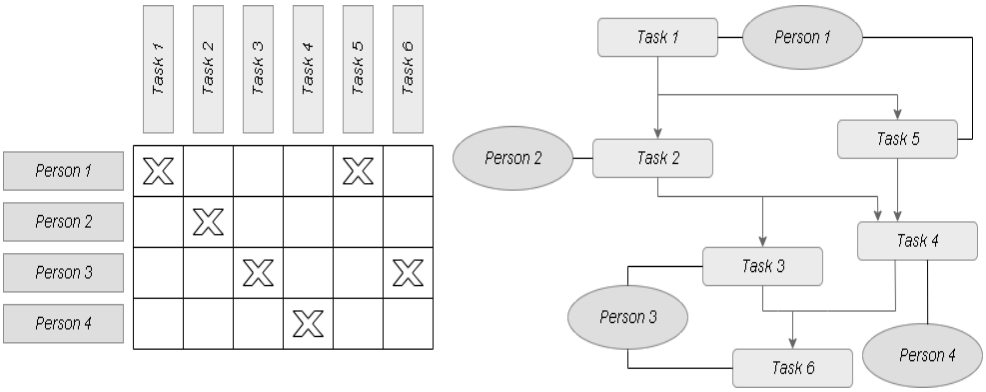


Fig. 7. Human resource management technology using a multi-domain matrix (DMM) *[13]*.

3 Results

DSM can also be applied to solve the problem of interaction managing with project stakeholders [14, p. 1]. The simulation results answer three fundamental questions for stakeholder management: what are the critical paths/themes for the project to engage other stakeholders? Who are the most important stakeholders for the project? How can the complexity of a large network relationships be intelligently managed?

Disadvantages of DSM. Along with significant advantages, this method also has some disadvantages:

- due to the representation of all data in the form of a matrix, the amount of data increases by nn times. Thus, the processing of such a data array requires more time and more computing power [15, p. 50].

- The presentation of data in the form of matrices is unusual for the perception and interpretation of a specialist dealing with certain functional areas of the project, so it is necessary to convert the processed data into a classic visual representation.

4 Discussion

Justification of the DSM application for constructing the structure of dependencies in domestic practice. The application of the DSM is an essential knowledge-intensive and effective tool in many areas of economic activity of business entities. The method is mutually compatible and intriguing with the classical methods of managing the functional projects areas. JSC Atomenergoproekt is engaged in research and development of software based on the dependency structure method for planning and controlling the design and construction of complex engineering facilities, taking into account foreign experience.

5 Conclusion

The paper considered the main features of the matrix method for constructing a dependency structure for planning and system analysis of complex engineering objects, as well as for managing human capital in the implementation of complex projects. The method is a powerful tool for analysis, optimization, search for optimal solutions and is used as a support system for decision makers. The algorithm for applying the method is implemented in various software and integrated into existing project management systems. The method is widely and effectively used in various sectors of the economy abroad, however, it has not received significant distribution in domestic practice.

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