MODULE 5

Design Structure Matrix (DSM)

Atila Ertas
Utku Gulbulak

2021

ATLAS Publishing

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Design Structure Matrix (DSM)

Every company has two organizational structures: The formal one is written on the charts; the other is the everyday relationship of the men and women in the organization.

Harold Geneen

5.1 Introduction

Design Structure Matrix (DSM) also referred to as dependency structure matrix is a tool for managing complexity. The initial DSM matrix corresponds to an adjacency matrix of ISM discussed in the previous module. DSM is a tool used in:

- complex systems management
- product development,
- project planning, management, and organizations
- system decomposition and integration

DSM helps the project team to agree on the design of a complex product in a timely manner and it helps to design a complex product to be modular so that portions of it can be more easily changed or modified.

Management of complexity using a DSM was initiated by Don Steward in 1981. The DSM is a method for picturing relations and dependencies within a certain activity.[1] It is a matrix-based tool that represents information flows that allow the representation of complex task (or team) relationships in order to determine a sensible sequence (or grouping) for the tasks (or teams) being modeled.[2]

[1]Danilovic, M. & Börjesson, H., "Managing Multi project Environment," The 3rd International Dependence Structure Matrix (DSM) Workshop, Proceedings, October 29-30, 2001, Massachusetts Institute of Technology (MIT), Massachusetts, Boston, Cambridge, USA.

[2]Ali A. Yassine, An Introduction to Modeling and Analyzing Complex Product Development Processes Using the Design Structure Matrix (DSM) Method. https://staff.aub.edu.lb/ ay11/DSM-Tutorial_English.pdf, accessed August 1, 2002.

5.2 Classification of DSM

As shown in Figure 5.1, there are four different types of DSM are used for different types of data:[3]

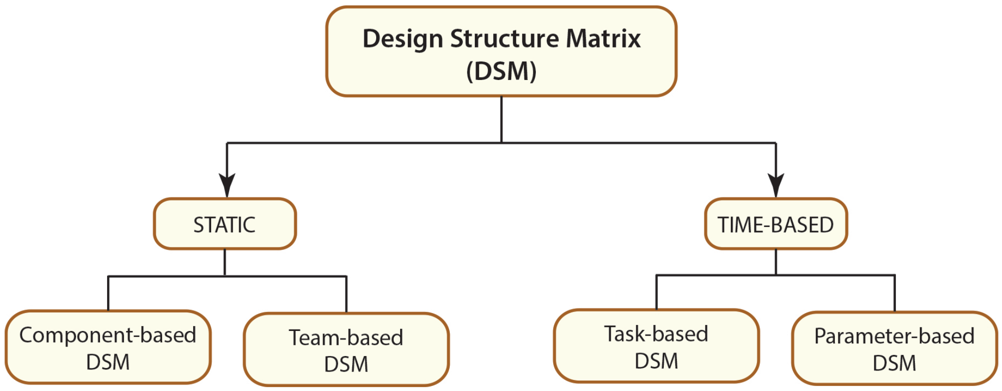


Figure 5.1: DSM types.

Component-based DSM: Analyzes relations and interactions among components in complex system architecture. An organized grouping of components will help to differentiate types of interactions. Four types of component grouping are shown in Table 5.1.[4,5]

Table 5.1: System component interaction types (4,5).

Special	Associations of physical space and allignment, needs for adjacency or orientation between two components
Energy	Needs for energy transfer/exchange between two components (e.g., power supply)
Information	Needs for data or signal exchange between two components
Material	Needs for material exchange between two components

As sown in Table 5.2, a quantification arrangement among the components enables weighting interactions relative to each other.[4,5]

[3]Tyson R. Browning,“ Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions,” *IEEE Transactions on Engineering Management,* Vol. 48, No. 3, 2001.
[4]T. U. Pimmler and S. D. Eppinger, (1994). Integration Analysis of Product Decompositions. in Proc. ASME 6th Int. Conf. on Design Theory and Methodology, Minneapolis, MN, 1994.
[5]Tyson R. Browning, (2001). Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions. *IEEE Transactions on Engineering Management,* Vol.48, No. 3 pp: 292-306.

Table 5.2: Spatial component interaction quantification arrangement (4,5).

(+2)→Required	Physical adjacency is necessary for functionality.
(+1)→Desired	Physical adjacency is beneficial, but not necessary for functionality.
(0)→Indefferent	Physical adjacency does not affect functionality.
(-1)→Undesired	Physical adjacency causes negative effects but does not prevent functionality.
(-2)→Undesired	Physical adjacency must be prevented to achieve functionality.

Team-based DSM: is used for complex organizational analysis to show interactions and information flow among organizational entities, design teams, and team members. Different types of interaction among the team members are shown in Table 5.3.[6]

Table 5.3: Different types of interaction among the team members.

Level of Detail	Sparse (documents, e-mail) to reach (models, face-to-face).
Frequency	Low (batch, on-time) to high (on-line, real).
Directions	One-way to two-way.
Timing	Early (preliminary, incomplete, partial) to late (final).

Task/activity-based DSM: analyzes relations among tasks or activities such as project scheduling and process modeling.

Parameter-based DSM: analyzes relationships among a set of design parameters in complex system architecture. Building and analyzing a parameter-based DSM is similar to an activity-based DSM.

Table 5.4 shows the applications of different types of DSMs.[7]

5.2.1 Design Dependencies

Figure 5.2 shows three possible dependencies among elements. Consider a sub-system that is composed of two elements: element “A”, and element “B”. The directionality of influence from one element to another is shown by an arrow.

In the parallel configuration shown in Figure 5.2(a), the elements do not interact with each other. Task B is said to be independent of task A and no information exchange is required

[6] The Design Structure matrix, https://dsmweb.org/different-dsm-types/, accessed August 2, 2020.

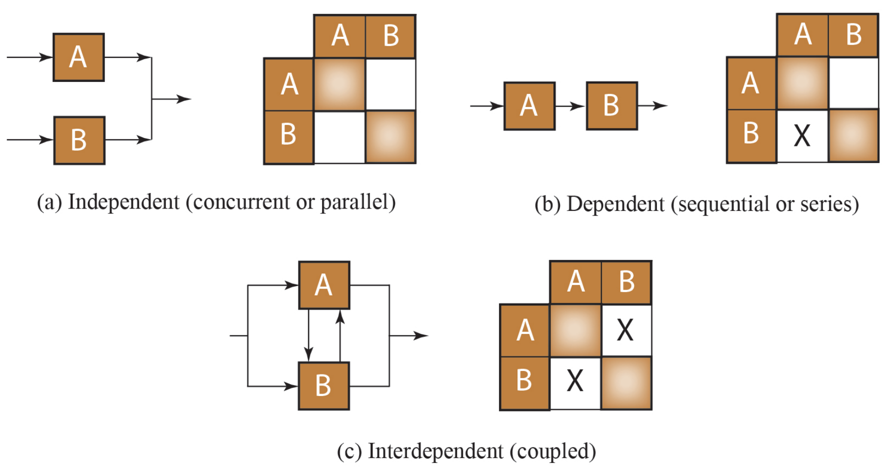
[7] Adapted from Bartolomei, J., Cokus, M., Dahlgren, J., de Neufville, R., Maldonado, D., Wilds, J. Analysis and applications of design structure matrix, domain mapping matrix, and engineering system matrix frameworks. Massachusetts Institute of Technology Engineering Systems Division. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.163.9694&rep=rep1&type=pdf

Table 5.4: DSM techniques for types of DSMs.

DSM Types	Representation	Application	Analysis method
Task-based	Task/Activity, input/otput, relationship	Project scheduling, activity sequencing	Partitioning, Tearing, Banding
Parameter-based (low level process)	Design parameter relationships	Low level activity sequencing & process construction	Partitioning, Tearing, Banding
Team-based (organization)	Teams organization and their relationships	Organizational design, interface management, team integration	Clustering
Component-based	Component relationship	System architecting, engineering design etc.	Clustering

between the two activities – both activities can start anytime independently without affecting each other.

In the sequential configuration shown in Figure 5.2(b), one element influences the decision of another element. For example, system parameters of element B are selected based on the system parameters of element A – task A should be performed before task B.



(a) Independent (concurrent or parallel)

(b) Dependent (sequential or series)

(c) Interdependent (coupled)

Figure 5.2: Dependencies among elements.

In the coupled system shown in Figure 5.2(c), the flow of information is intertwined: the activities of element A influence the activities of element B, and element B influences A. This would occur when activities of element A could not be determined without first knowing element B and B could not be determined without knowing element A. This type of dependency is called "Circuit" or "Cycle" as explained in the first Module.

5.2.2 Matrix-Based Systems Modeling

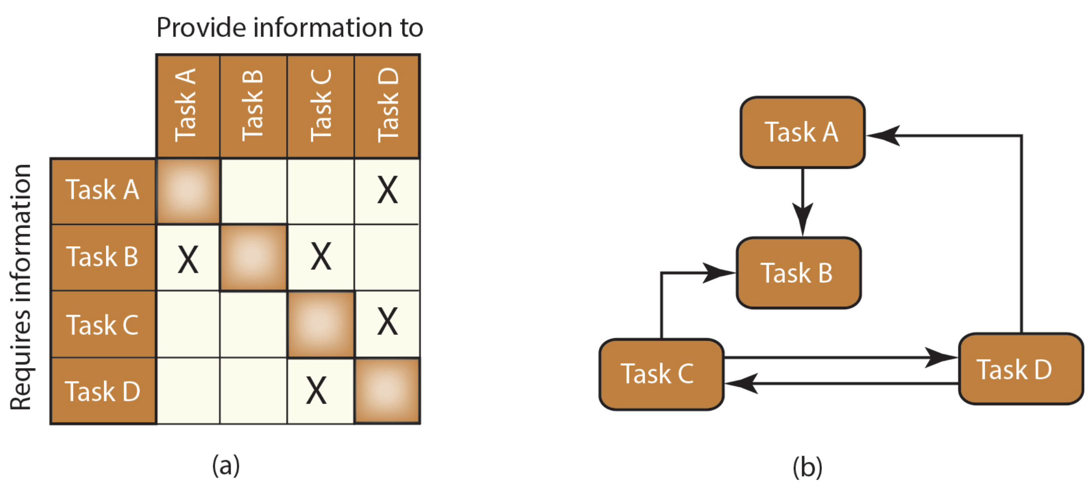
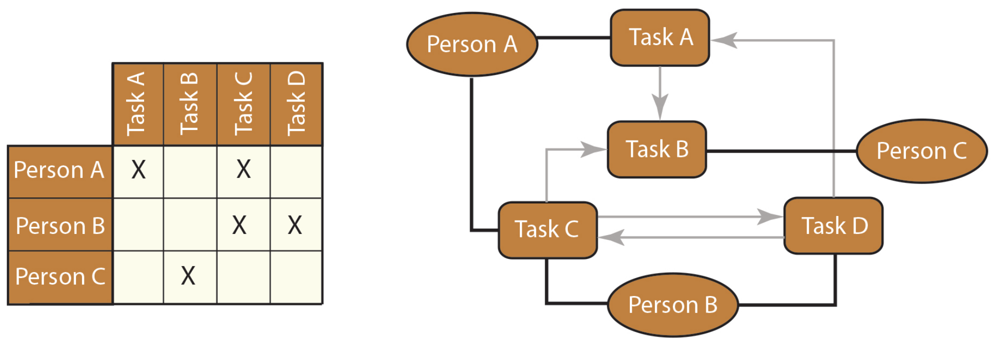


Figure 5.3: Dependencies among DSM elements.

DSM is the graphical representation of a matrix. An example of DSM is shown in Figure 5.3. It is a basic matrix used to show relationships of entities of one kind to each other, for example, task to task.[8] A DSM is arranged by listing all tasks as rows and columns in square $n \times n$ matrix, where n is the number of tasks. The tasks are placed in the matrix close to the order they should be completed. DSM can be symbolized as binary (shows the existence of a relation), or numerical (represent the strength of a relation). Note that diagonal elements have no significance in DSM.

Figure 5.3(b) shows a simple process consisting of four task activities which shows the corresponding information exchange patterns – which tasks provide input to others and which tasks are coupled and thus require iteration. For example, in Figure 5.3(a), A provides information to B and D provides information to A, and tasks C and D are coupled (cycle). In short," Xs" indicate column tasks provide direct input to corresponding row tasks.

[8]Steward, D.V. The design structure system: A method for managing the design of complex systems. IEEE Transactions on Engineering Management, 1981, 28, 71–74.



(a) (b)

Figure 5.4: Domain mapping matrix.

Domain Mapping Matrices (DMM) shown in Figure 5.4(a) is an extension of DSM which includes domain mapping between two domains. For example, tasks for people or activities for people. Figure 5.4(b) shows how these people (team members) can be mapped to certain task activities. DMM is a rectangular matrix.

	Scheduling/ Planning	Risk Analysis	Production	Testing	Budget	• • •	• • •	• • •
John	A	R	A	A				
Mark	R				A			
Jesse			R					A
Person					R			
Person							R	
• • •						A		

Figure 5.5: Distributing responsibilities through domain mapping matrix.

Figure 5.5 shows the distributions of responsibilities to perform a design project. In this figure **R** indicates the responsible person who does the work to complete the task. **A** indicates that the person is finally accountable for the correct and thorough completion of the task (signs and approves the work that the responsible provides). Accountable could be a project leader.

Multiple Domain Matrix (MDM) which combines DSM and DMM was proposed by Eppinger and Salminen to show the interactions among different types of dependencies and domains as shown in Figure 5.6.[9] The modeling of complex systems often requires modeling of multiple domains with different aspects (people, activities, etc.). In complex system analysis, DSM can be limited to meet the demands of extensive information exchanges across the entire engineering system. MDM is used to model entire systems consisting of multiple domains, each having multiple elements, connected by different relationship types.[10] The MDM includes DSMs along its diagonal and DMMs outside the diagonal Figure 5.6.

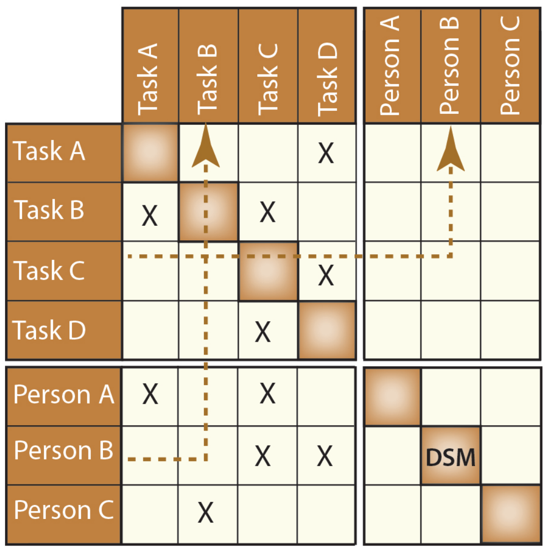


Figure 5.6: Multiple domain matrix.

5.3 Design Structure Matrix Partitioning

Figure 5.7 shows an example of partitioning for a matrix of twelve activities (tasks.)[11] Figure 5.7(a) shows the unpartitioned DSM in its initial form. As seen from Figure 5.7(a), task E requires information from tasks F, H, and K. Task B transfers information to tasks C, F, G, J, and K. Figure 5.7(b) shows the partitioned matrix after being manipulated in order to move the "Xs" to lower triangle or move as close as possible to the diagonal of the matrix.

The process of the partitioning of a DSM is performed by reordering DSM rows and columns so that the new DSM turns out to be a block-diagonal matrix (i.e., a lower triangular matrix). However, for complex engineering systems, it is difficult to have a lower triangular matrix by

[9]Eppinger, S.D., and Salminen, V., "Patterns of product development interactions," International Conference on engineering design, ICED 01, Glasgow, 21-23 August 2001.

[10]Maurer, M., Structural awareness in complex product design. Dissertation, Technischen Universität, München, Germany, 2007.

[11]Adapted from Yassine, A., and Braha, D., "Complex Concurrent Engineering and the Design Structure Matrix Method, Concurrent Engineering," *Research and Applications,'* Volume 11 Number 3, pp. 165-176, 2003.

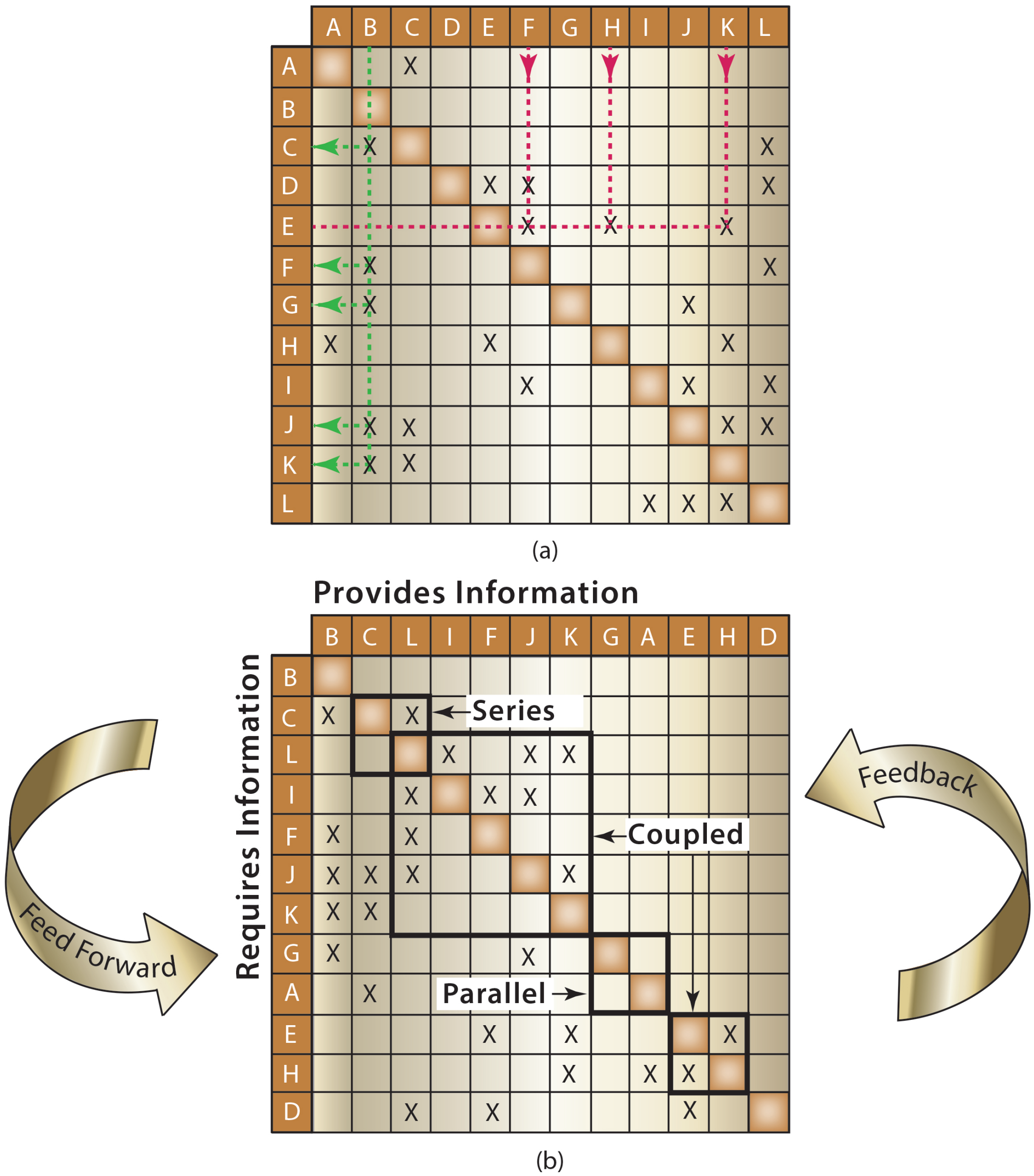


Figure 5.7: (a) Base DSM; (b) Partitioned DSM. (Adapted from: Yassine, A., and Braha, D., "Complex Concurrent Engineering and the Design Structure Matrix Method, Concurrent Engineering," *Research and Applications,'* Volume 11 Number 3, pp. 165-176, 2003.)

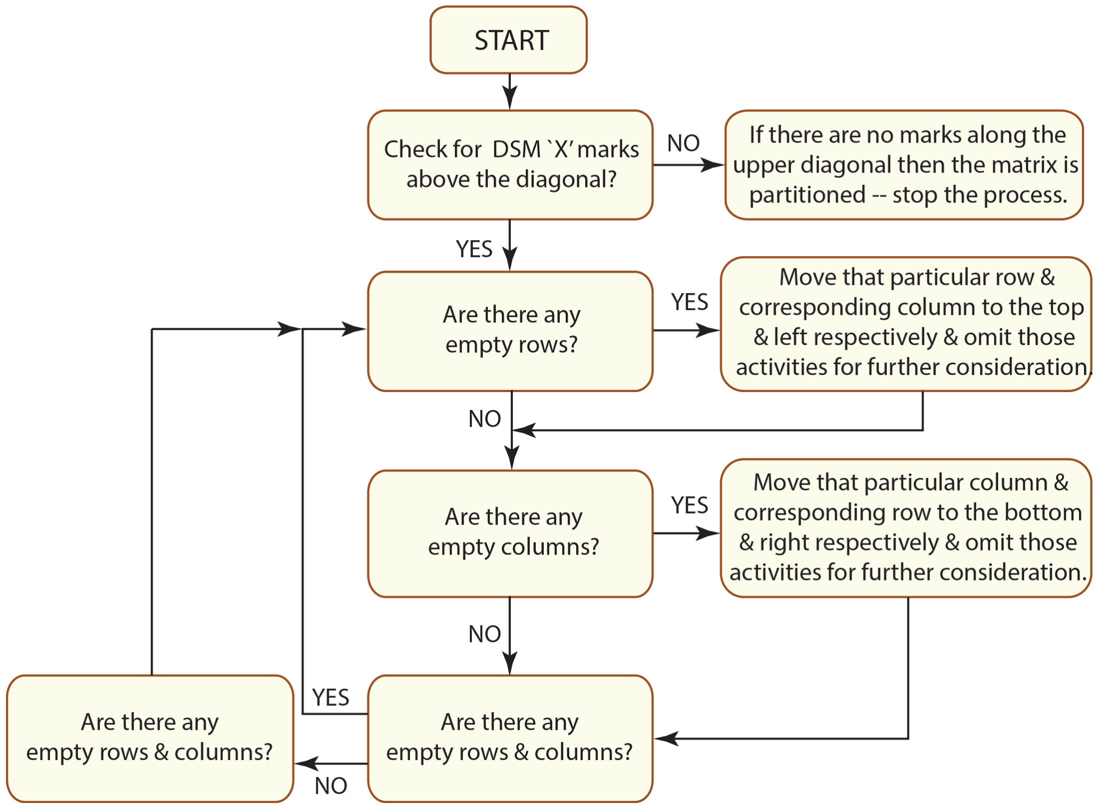


Figure 5.8: Process of partitioning of DSM.

simple manipulation of rows and columns.[12] Above the diagonal of DSM (upper triangular matrix), marks of feedback or cycles are not desirable – requires time-consuming iterations.

Once the DSM is partitioned as shown in Figure 5.7(b), tasks in series are identified and executed sequentially and parallel tasks are executed concurrently. Execution of coupled tasks requires iteration by assuming a proper initial guess.

As seen from the flowchart given in Figure 5.8, the steps for the partitioning process are given as follows:[13]

1. Check for the existence of any 'X' mark along the upper diagonal of the DSM matrix. If there are no marks along the upper diagonal then the matrix is partitioned. Hence, stop the procedure.
2. Check for empty rows in the DSM matrix and move all those empty rows to the top of the matrix and the corresponding columns to the left of the matrix and remove them from the

[12] Moraes, N. A. Compreensão e Visualização de Projetos Orientados an Objetos com Matriz de Dependâncias, Universidade Federal da Bahia, 2007.

[13] A. Ertas, (2018). *Transdisciplinary Engineering Design Process.* John Wiley &Sons, Inc.

DSM for further consideration.

3. For the remaining matrix, check for any empty columns and move all those empty columns to the right and the corresponding rows to the bottom of the DSM matrix and remove them from the DSM for further consideration.
4. Repeat steps 2 & 3 until there are no empty rows & columns in the DSM matrix.
5. Using the path searching method identify cycles/loops and collapse the elements involved in a single one composite element then go to step 2.

5.3.1 Design Structure Matrix Tearing

Tearing is the process of reordering of coupled tasks within a group (block) to find an initial ordering to start the iteration process.[14] Once coupled tasks are identified in a DSM, they are subjected to the next level of analysis – that is DSM *tearing*: identifying some of the feedback marks which have the least impact on the system design that can be removed from the matrix. Although tearing may help to reduce the complexity and size of the cluster and speed up the design process, the expense is a loss of information. That is why the number of tears should be kept to a minimum to avoid relying too much on initial guesses.

There is no optimal method exists for tearing, but when making tearing decisions the following criteria are recommend:[5,15]

- ***Minimal number of tears:*** since tears represent an approximation or an initial guess to be used; it is advisable to reduce the number of guesses used in the tearing process.
- ***Limit tears to the smallest blocks along the diagonal:*** it is desirable to limit the inner iterations to a small number of tasks.

The process of tearing is based on guessing and assumptions. Thus, tearing should not be done unless absolutely necessary.[16]

5.3.2 Design Structure Matrix Banding

DSM banding is an alternative to DSM partitioning to identify the sets of independent (i.e. parallel or concurrent) elements.[17] As shown in Figure 9, alternating dark and light, there are five bands in the partitioned matrix. It is similar to partitioning the DSM using the Reachability Matrix Method without considering the feedback marks (a band corresponds to a level). As shown in Figure 5.9 (Yassine, 2004), each band consists of grouping activities that are independent and they do not depend on each other for information. For example, element 10 doesn't provide any

[14] G. Kron, 'Diakoptics', piecewise solution of large scale systems of equations. Ph.D. Thesis, University of Texas, Austin, 1963.

[15] Ali A. Yassine, "An Introduction to Modeling and Analyzing Complex Product Development Processes Using the Design Structure Matrix (DSM) Method," *Urbana,* Vol. 51, Issue: 9, pp. 1-17, 2004.

[16] Bartolomei, J., Cokus, M., Dahlgren, J., de Neufville, R., Maldonado, D., Wilds, J., Analysis and applications of design structure matrix, domain mapping matrix, and engineering system matrix frameworks, Massachusetts Institute of Technology Engineering Systems Division, pp. 1-37

[17] Grose, David L., "Reengineering the Aircraft Design Process", Proceedings of the Fifth AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Panama City Beach, FL, Sept. 7-9, 1994.

information to element 5 and also element 5 doesn't require any information from element 10. Another example is, in row 5 there are three independent parameters and they do not depend on each other for information; therefore, they belong to the same band. The group of bands or levels within a DSM represent the critical path of the system. The fewer bands provide less concurrency and complexity in the project. A large number of bands indicates that the project is highly interdependent and complex.

	2	3	12	9	6	10	11	7	1	5	8	4
2	2											
3	X	3	X									
12			12	X		X	X					
9			X	9	X	X						
6	X		X		6							
10	X	X	X			10	X					
11	X	X					11					
7	X					X		7				
1		X							1			
5					X		X			5	X	
8							X		X	X	8	
4			X		X					X		4

Figure 5.9: DSM Banding.

EXAMPLE 5.1

Figure 5.10 shows the relationships of four tasks. Using topological sorting and path searching method partition DSM matrix shown in Figure 5.10.

SOLUTION

	Task A	Task B	Task C	Task D
Task A			X	
Task B			X	X
Task C	X			X
Task D				

Figure 5.10: Unpartitioned DSM matrix.

As shown in Figure 5.10, there are four tasks in the upper triangular matrix. The following steps are used for partitioning the DSM matrix (see flowchart given by Figure 5.8):

(1) As shown DSM matrix in Figure 5.11 (a), Task D in row D is empty – this task does not require any information from any other task shown in the DSM matrix. Thus, schedule Task D to the top of the matrix and the corresponding column Task D to the left of the matrix and then remove it from the DSM. (see Figure 5.11(b) – row D and column D are blocked with dark black lines).

(2) As seen from Figure 5.11(b), Task B in column B is empty – for the same reason we mentioned in item(1), move Task B to the right, and the corresponding row B to the bottom of the DSM and remove them from the DSM for further consideration (see Figure 5.11(c) – column B and row B are blocked).

(3) Figure 5.11(c) shows that there are no more empty rows and empty columns left. There is a circle (cycle) between Task A and Task C. In other words, Task C provides information to Task A and Task A requires information from Task C. Since such a circle is identified and clustered on the diagonal of the DSM, the partitioning process ends. Final partitioned DSM matrix is shown in Figure 5.11(d). Note that, when rows and columns are reordered check for original relationships as in Figure 5.10 among the tasks remain the same.

EXAMPLE 5.1 (Continued)

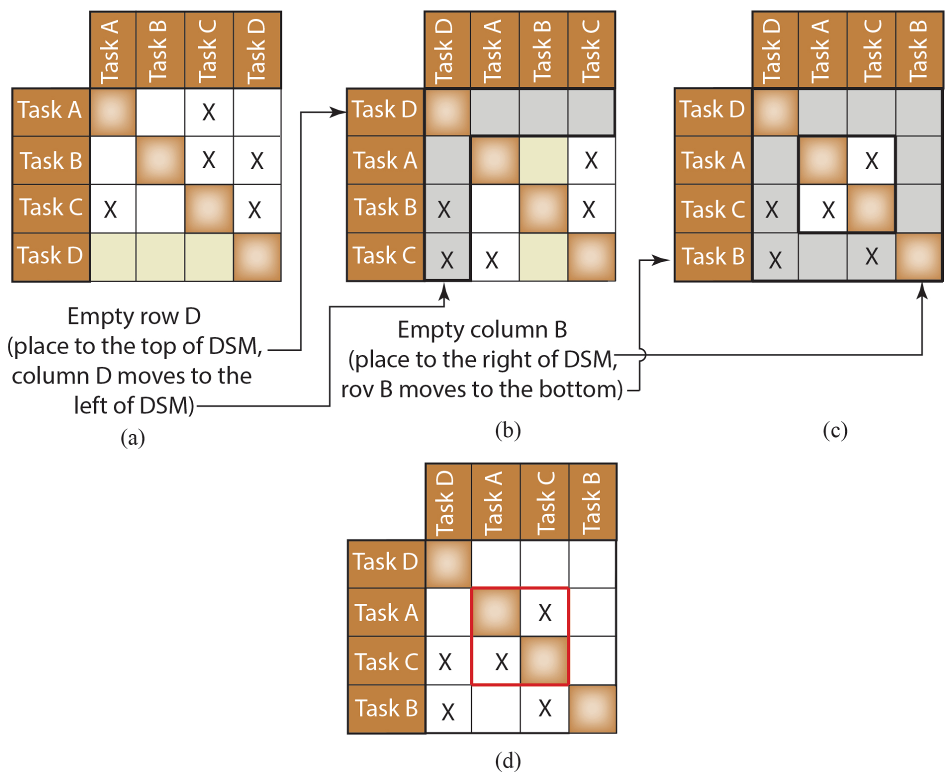


Figure 5.11: DSM partitioning.

EXAMPLE 5.2

Figure 5.12 shows the tasks rearrangement of Example 5.1. Using topological sorting and path searching method partition DSM matrix shown in Figure 5.12.

SOLUTION

	Task A	Task B	Task C	Task D
Task A		X		X
Task B				X
Task C	X			X
Task D				

Figure 5.12: Unpartitioned DSM.

Following the same procedure as in Example 5.1, the partitioned DSM is given in Figure 5.13(d). As seen from the figure, the partitioned matrix is a lower triangle matrix. Therefore, all the tasks could run in the defined order without iterations.

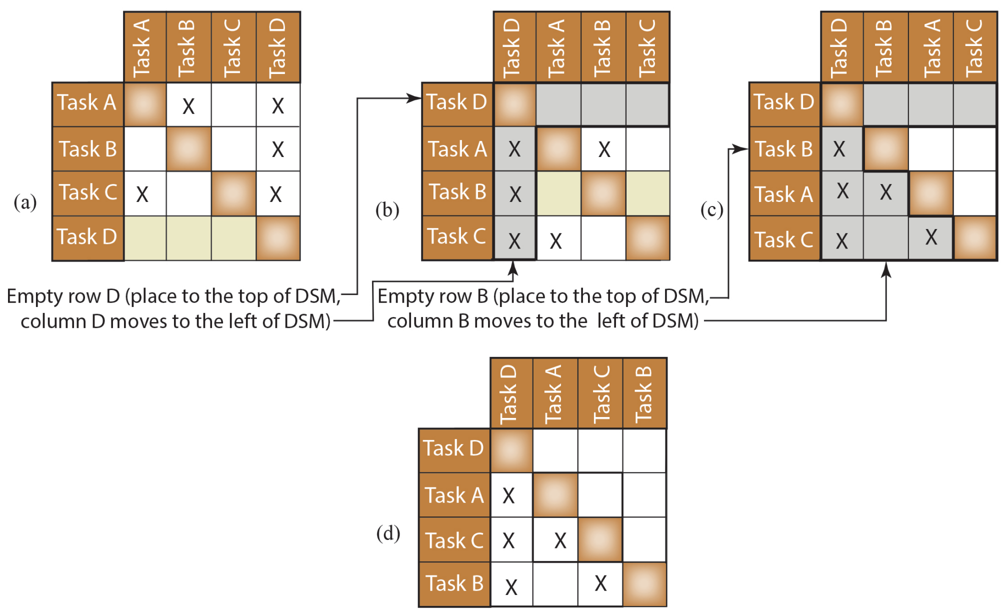


Figure 5.13: Partitioned DSM.

EXAMPLE 5.3

Assume that a team of seven students working on a design project. Use team-based DSM to show the information flow between the members within the sub-teams and the information flow (or interactions) among the sub-teams.

ANALYSIS

Team has following three sub-teams.

Team A = Members 1, 5, and 6

Team B = Members 4 and 5

Team C= Members 2, 3, 4, and 7

As shown in Figure 5.14, from the sub-team members list, the team-based DSM can be constructed. For example, from Team A team member 1 has a relationship with members 5 and 6 (see row #1 of DSM). Relationship of the team member 4 is through members 5 from Team B and also through members 2, 3, and 7 from Team C (see row # 4 of DSM).

	1	2	3	4	5	6	7
1					X	X	
2			X	X			X
3		X		X			X
4		X	X		X		X
5	X			X		X	
6	X				X		
7		X	X	X			

Figure 5.14: Rocket competition sub-team.

(a) **Partitioning**

DSM shown in Figure 5.14 can be partitioned to see the information flow among the team members within the sub-teams and the interactions between the sub-teams. For this case, we will manipulate rows and columns of the DSM shown in Figure 5.14 for the partitioning process to eliminate any feedback loops in the upper triangle of the matrix.

First, replace rows 2 and 3 with rows 5 and 6 as shown in Figure 5.15(b). This manipulation is logical because we would like to bring members of Team A together. Note that, the relationships of the members in the reorganized matrix remain the same as the original matrix.

EXAMPLE 5.3 (continued)

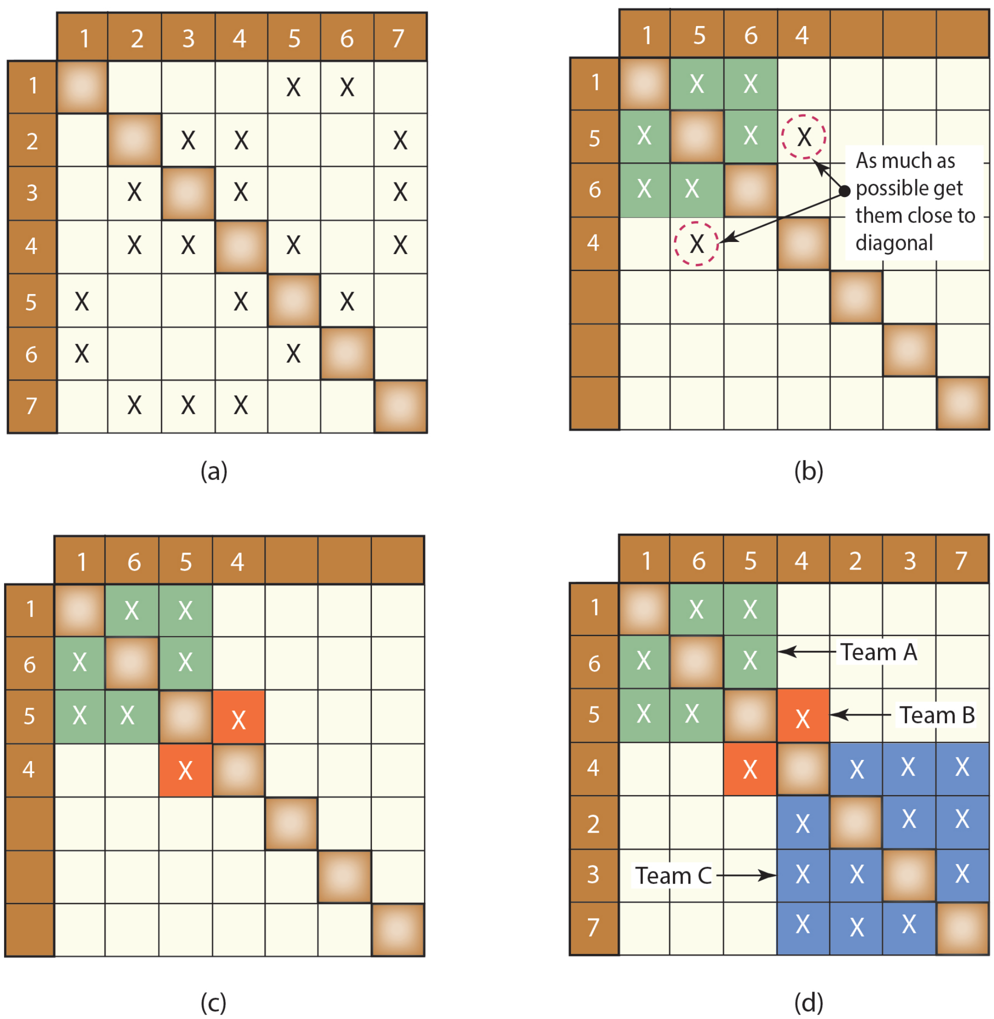


Figure 5.15: Sub-team partitioning.

Second step is to bring coupled entities 4 and 5 close to diagonal (see Figure 5.15(b)). To accomplish this, swap the places of row 5 and row 6 (see Figure 5.15(c)).

EXAMPLE 5.3 (continued)

The last step is to include remaining team members 2, 3, and 7 belonging to Team C. As seen from Figure 5.15(d), three teams are clustered along the diagonal of the DSM to highlight the inter-team interfaces. These clusters represent sub-team members that are closely interconnected. The exchange of information among the teams is also shown in Figure 5.15(d). Team B is the communication bridge between Team A and Team C, in other words interacting with Team A and also interacting with Team C.

(b) **Frequency of Team Interactions**

Figure 5.16 shows the frequency of interactions (daily, weekly, and monthly) within the teams and among the teams.

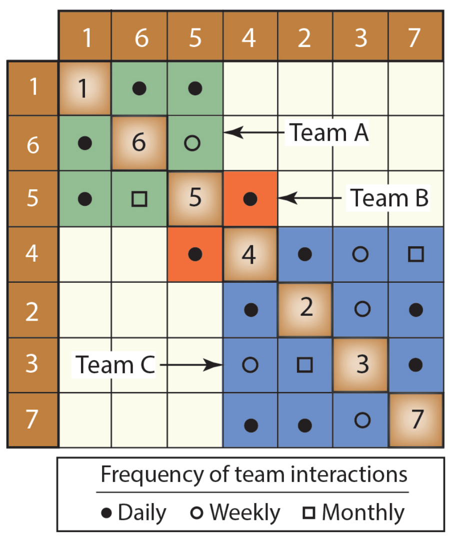


Figure 5.16: Frequency of team interactions.

In designing complex systems or products mistakes or failures can be avoided by making sure that team members or different teams responsible for development have the opportunity to communicate effectively.

Team members or teams working on a different part of a system or product must integrate their designs by frequent information exchange and communication with those the other team members to make sure that the entire system or product will function properly as a whole.

EXAMPLE 5.3 (Continued)

(c) **Mapping the Teams to Project Activities**

it is important to map the team members to system or product development tasks as shown in Figure 5.17 – as an example, in this case, design and development, component testing, and manufacturing & documentation.

	TASKS										
	Design and development				Components testing				Manufacturing & documentation		
	Project planning	Detail drawings	Simulation	Detail design	Electronics	Staging	Safety	Testing	Manufacturing	Budgeting	Documantation
Member 1	A	R	R	R							
Member 2									A	R	R
Member 3									R	A	R
Member 4					A	R	A	R	R	R	R
Member 5	R	A	R	R	R	A	R	A			
Member 6	R	R	A	A							
Member 7									R	R	A

Figure 5.17: Responsibility assignment matrix.

In Figure 5.17, **"R"** designates "Responsible" person who does the work to complete the task – they are responsible for implementation of a project. Responsibility can be shared as shown in Figure 5.17. The degree of responsibility is assigned by the person who is "Accountable."

"A" designates the person finally accountable for the correct and thorough completion of the task (signs and approves the work that responsible provides) – that is the person who is ultimately answerable for the decision to be made – the person who will take decisions and who will be blamed if something goes wrong?

EXAMPLE 5.3 (Continued)

In general, the manager of the project or office will be designated as the accountable person. However, as shown in Figure 5.17, there could be several accountable people for complex systems and product development. Usually, we should have a minimum number of people accountable for every task.

> "This is a story of four people named Everybody, Somebody, Anybody, and Nobody. There was an important job to be done and Everybody was asked to do it. Everybody was sure Somebody would do it. Anybody could have done it, but Nobody did it. Somebody got angry about that because it was Everybody's job. Everybody thought Anybody could do it, but Nobody realized that Everybody wouldn't do it. It ended that Everybody blamed Somebody when Nobody did what Anybody could have done."
>
> **Charles R. Swindoll**

5.4 Complex System Design

Although the definition of complex systems is very broad, for the purpose of this module we will define complex systems as a system composed of many components which may interact with each other and contain feedback loops.

For example, consider a two-stroke marine engine power system shown in Figure 5.18. The 2-stroke marine engine is the main driving power source and also the largest machinery on a ship. A huge amount of effort, resources, and time is devoted to ensuring that this huge engine runs smoothly and efficiently, taking the ship from one port to another without failures. Considering the complexity and number of parts the 2-stroke marine engine power system has (see Figure 5.18), the operation of this system is not an easy task.

As seen from Figure 5.18, the 2-stroke marine engine power system has three sub-systems – fuel supply sub-system, steam supply sub-system, and fuel oil injection sub-system. Figure 5.19 shows a simplified version of two sub-systems, namely, the fuel supply sub-system and steam supply sub-system. As seen from this figure, interactions within the sub-systems and among the sub-systems are evident. The next case study which will be presented in this section is good for describing and understanding the nature of those interactions.

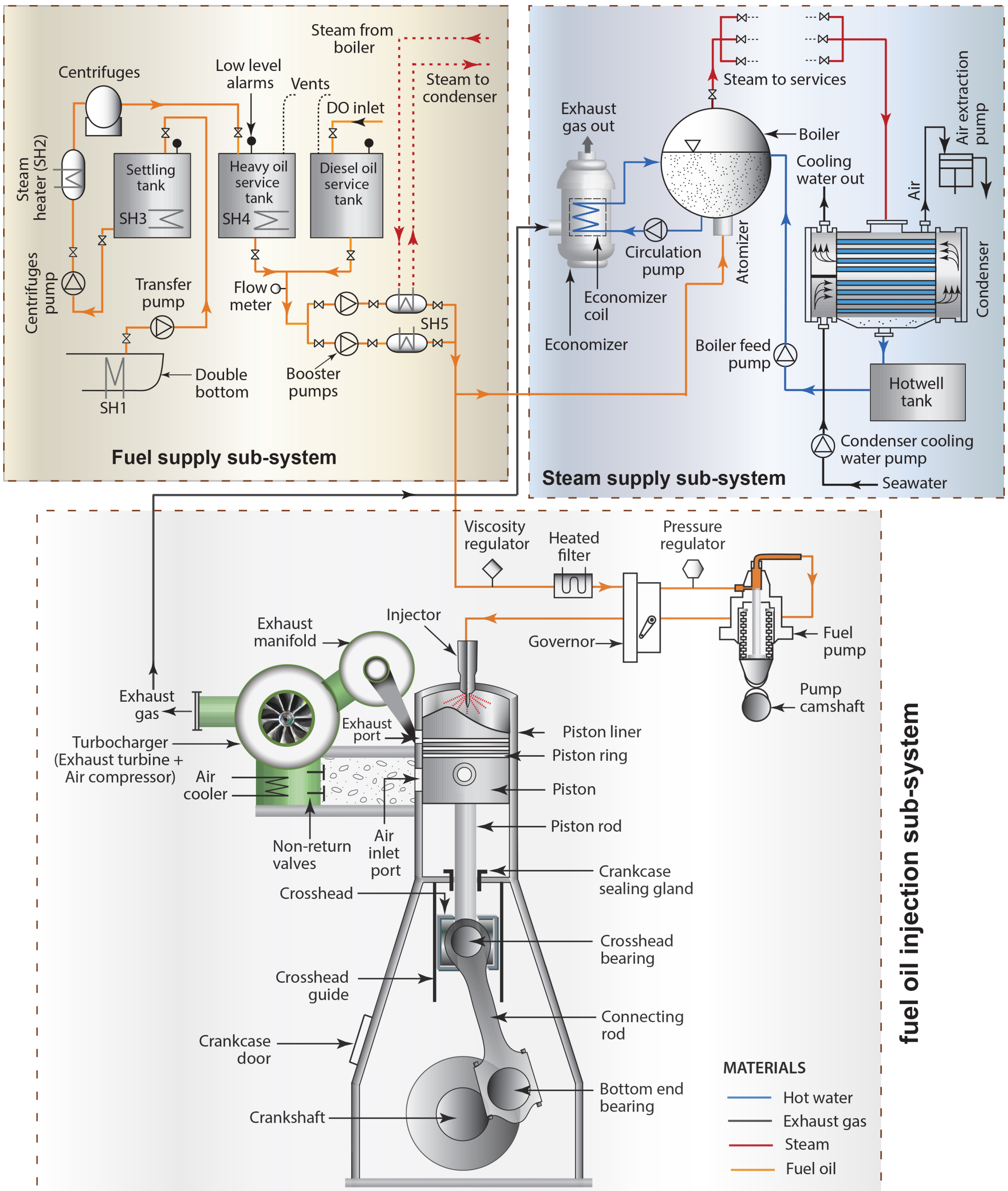


Figure 5.18: Two cycle marine diesel engine power system.

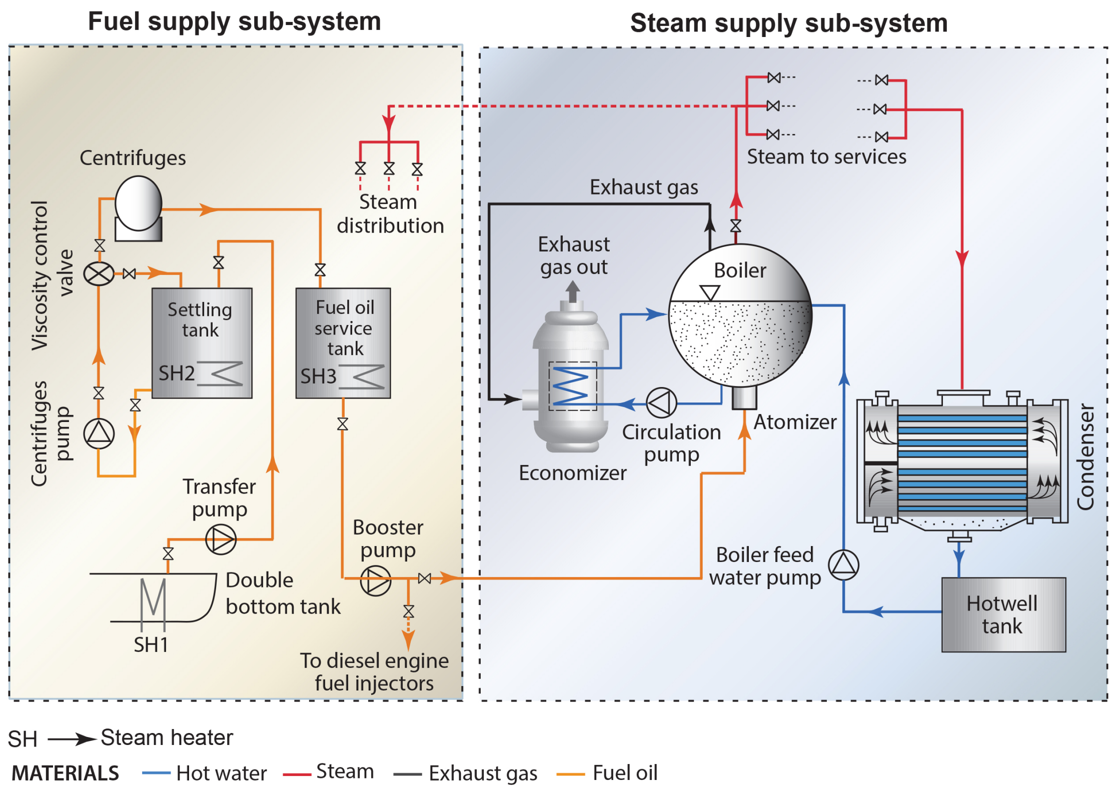


Figure 5.19: Fuel/Oil and boiler sub-systems.

CASE STUDY 5.1

Select the proper system components to design and build the sub-systems given in Figure 5.19 and investigate the interactions within and among the sub-systems. Complete the system analysis following Figure 5.20.[a]

ANALYSIS

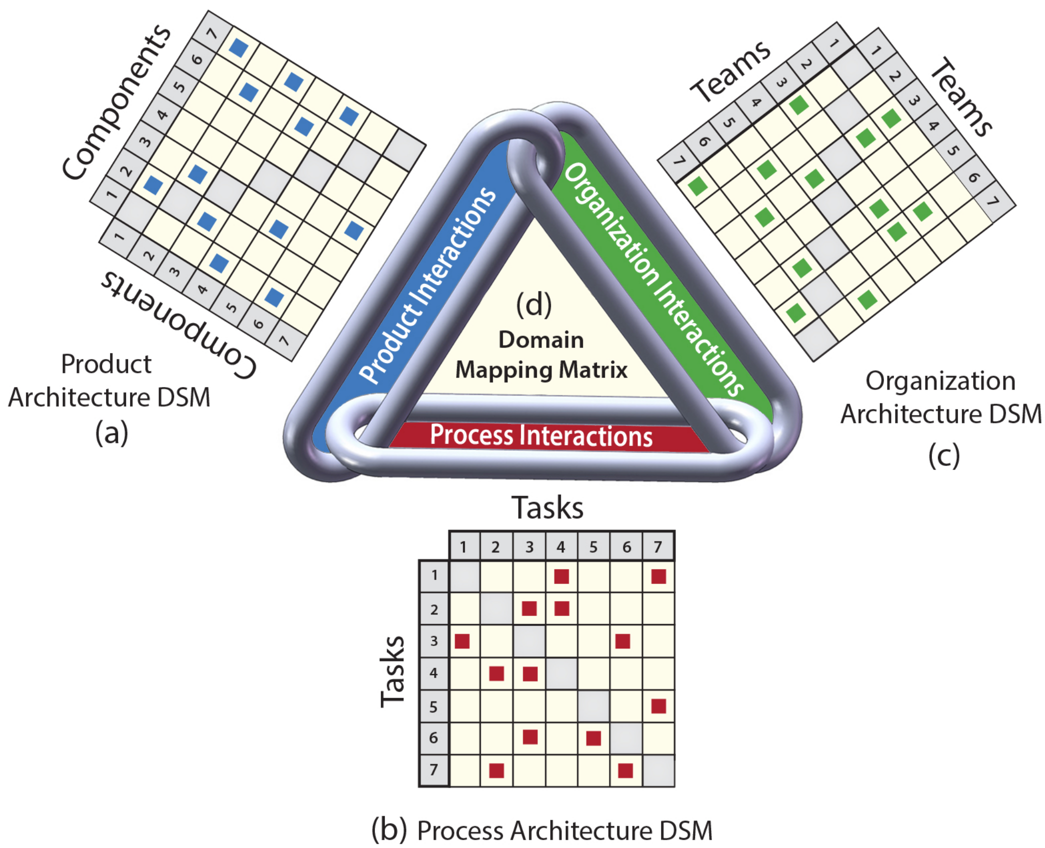


Figure 5.20: Creating DMMs from three basic DSMs.[b]

[a] Adapted from senior design project submitted to Dr. A. Ertas by Spencer Yancey, (2020). Two Cycle Diesel Engine Power System. Mechanical Engineering Department. Texas Tech University.
[b] Adapted from Steven D. Eppinger and Tyson R. Browning, (2012). *Design Structure Matrix Methods and Applications.* The MIT Press Cambridge, Massachusetts London, England.

CASE STUDY 5.1 (continued)

(a) **Product (or system) Architecture DSM**

Using Figure 5.19, sixteen components that affect the functionality of the sub-systems are identified for the analysis. Interactions between the components are designated by "numbers" instead of "X" marks in the DSM matrix as shown in Figure 5.21.

Component Base DSM / COMPONENTS		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
		Double bottom	Settling tank	Fuel oil service tank	Transfer pump	Centrifuges pump	Viscosity control valve	Booster pump	Centrifuges	Steam heaters (SH1-3)	Atomizer	Boiler	Economizer	Circulation pump	Main feed pump	Condenser	Hotwell tank
Double bottom	A	A			2					2							
Settling tank	B		B		2	2				2							
Fuel oil service tank	C			C				2	2	2							
Transfer pump	D	2	2		D												
Centrifuges pump	E		2			E	2										
Viscosity control valve	F					2	F		2								
Booster pump	G			2				G			1						
Centrifuges	H			2			2		H								
Steam heaters (SH1-3)	I	2	2	2						I							
Atomizer	J							1			J	2					
Boiler	K									1	2	K	2		2		
Economizer	L											2	L	2			
Circulation pump	M											2	2	M			
Main feed pump	N											2			N		2
Condenser	O									1						O	2
Hotwell tank	P														2	2	P

2 Relationships by energy exchange between two elements

2 Relationships by material exchange between two elements (physical adjacency)

1 Relationships by material exchange between two elements (no physical adjacency)

Figure 5.21: Product architecture DSM (identifies component interactions).

CASE STUDY 5.1 (continued)

Using Figure 5.21, partitioned matrix for the system components developed (see Figure 5.22. Different types of relationships between the components are defined in the legends of Figure 5.21 and Figure 5.22.

Component Base DSM Partitioned

COMPONENTS		Double bottom	Settling tank	Light oil service tank	Transfer pump	Centrifuges pump	Viscosity control valve	Booster pump	Centrifuges	Steam heaters (SH1-3)	Atomizer	Boiler	Economizer	Circulation pump	Main feed pump	Condenser	Hotwell tank
COMPONENTS		A	D	B	E	F	H	C	G	I	J	K	L	M	N	P	O
Double bottom	A	A	2							2							
Transfer pump	D	2	D	2													
Settling tank	B		2	B	2					2							
Centrifuges pump	E			2	E	2											
Viscosity control valve	F				2	F	2										
Centrifuges	H					2	H	2									
Fuel oil service tank	C						2	C	2	2							
Booster pump	G							2	G		1						
Steam heaters (SH1-3)	I	2		2						I							
Atomizer	J								1		J	2					
Boiler	K									1	2	K	2	2	2		
Economizer	L											2	L	2			
Circulation pump	M											2	2	M			
Main feed pump	N											2			N	2	
Hotwell tank	P														2	P	2
Condenser	O									1						2	O

2 Relationships by energy exchange between two elements

2 Relationships by material exchange between two elements (physical adjacency)

1 Relationships by material exchange between two elements (no physical adjacency)

Figure 5.22: Sub-system components partitioned matrix.

CASE STUDY 5.1 (continued)

(b) **Process Architecture DSM**

Using Figure 5.19, tasks descriptions and requirements are defined as follows.

TASK DESCRIPTIONS

Component selections: Selection of a preexisting manufactured component or the selection of a bespoke design based on the fuel oil and water properties at that point in the system.

Steam Distribution: Determining the percentage of the boiler output that is going to be routed to specific tasks that rely on steam delivery (steam to services and steam distribution from the boiler).

Diesel Engine Requirement: Determining the fuel oil mixture properties that the diesel engine requires for optimum operation.

Viscosity Requirement: The monitoring of the fuel oil viscosity that each individual component needs for optimum performance and how the fuel oil viscosity changes as it travels through the system.

Overall System Efficiency: The determination of the ratio of system output (steam and exhaust) to system input (fuel oil and water) so that running cost can be estimated.

Overall System Flow Rate: The determination of the amount of fuel oil being consumed every hour so that the total time of operation per tank can be estimated. The determination of how much time passes from the commencement of boiler heating to max steam production occurring.

TASK INTERACTION DESCRIPTIONS (INFORMATION REQUIREMENTS)

Steam Distribution: None: The volume of steam needed by each service in the engine compartment and the steam heaters of the system is assumed to be known.

Diesel Engine Requirement: Note: The fuel oil properties required for the engine to combust optimally are assumed to be known.

Boiler Selection

Steam Distribution: The volume of steam required by each steam dependent service dictates the output capability of the boiler.

Atomizer Selection: The heat generation capability of the atomizer will dictate the water volume of the boiler required so that an acceptable time interval passes from heat production to steam production.

CASE STUDY 5.1 (continued)

Steam Heater Selection

Steam Distribution:The higher the volume of steam output from the boiler not being sent to the steam heaters will increase the time interval from steam leaving the boiler to the steam heaters reaching their operating temperatures.

Boiler Selection: The performance of the boiler will dictate what kind of steam heaters must be selected; a good boiler will require cheaper steam heaters while a poor boiler will require more expensive steam heaters to make up for the boiler's shortcomings.

Atomizer Selection

Diesel Engine Requirement: The atomizer is fed fuel/oil in parallel with the diesel engine therefore the properties of the fuel/oil required by the diesel engine are going to dictate the combustion of the atomizer.

Boiler Selection: The size and shape of the boiler is going to dictate what kind of atomizer design will most efficiently heat the boiler through combustion.

Fuel Oil Pump Selections

Diesel Engine Requirement: The diesel engine will require the fuel oil at a certain pressure for optimum combustion and efficiency.

Centrifuge Selection: The centrifuges will need to be supplied with fuel oil at a certain pressure for optimum separation to occur in a timely manner.

Fuel Oil Tank Selection: The fuel oil must be pressurized enough to flow through the viscosity control valve, and centrifuges, and still fill the light oil service tank at the same rate fuel/oil leaves the tank to supply the diesel engine and atomizer.

Settling Tank Selection: The transfer pump selection is dictated by the settling rate of the highly viscous fuel/oil pumped out of the double bottom and must keep the tank full.

Centrifuge Selection

Fuel Oil Pump Selection: The centrifuges selected must be designed to operate at the incoming pressure and velocity of the fuel oil being pumped by the centrifuge pump for the optimum removal of impurities to occur.

Viscosity Requirement: The centrifuges must be selected to work with the viscosity of the fuel/oil at that point in the system because the viscosity of the fuel/oil will determine how fast they operate and how much wear they will experience.

CASE STUDY 5.1 (continued)

Fuel Oil Tank Selection

Diesel Engine Requirements: The fuel oil requirements of the diesel engine with respect to viscosity and flow rate will dictate the size of the light oil tank to ensure that the fuel oil supply is constant. If the tank is too large the steam heater will not be able to maintain the fuel oil temperature needed for the required viscosity.

Atomizer Selection: The fuel oil tank will need to supply fuel oil to the atomizer at a constant flow rate and must be taken into consideration when selecting the size of the tank.

Viscosity Requirement: The viscosity of fuel oil entering the light oil tank must be within the allowable range for the steam heater to lower the viscosity further during the time interval until it is pumped out to the diesel engine and atomizer.

Viscosity Requirement

Diesel Engine Requirements, Atomizer Selection, Fuel/Oil Pump Selection, Centrifuge Selection, Light Oil Tank Selection, Settling Tank Selection.

The viscosity of the fuel oil entering the two tanks must be within an allowable range to allow the steam heaters acting on those tanks to lower the viscosity to an allowable exit value to the other components. The components supplied by the tanks are designed to operate optimally with a certain fuel oil viscosity and if that is not achieved the wear will be higher and the efficiency will be lower. The objective of the components is to deliver the correct fuel oil viscosity and pressure to the diesel engine and the atomizer and they must meet those requirements.

Settling Tank Selection

Diesel Engine Requirement: The settling tank must yield a high enough percentage of lowered viscosity fuel oil, from the double bottom, allowed through the viscosity control valve to continue to the diesel engine to meet the max requirement of the diesel engine. The volume of the tank and the flow rate must be large enough that the diesel engine receives its fuel oil requirement.

Fuel Oil Tank Selection: The fuel oil tank must maintain a level of fuel oil to allow for constant running for a specified number of hours and as such, the settling tank must keep up with the discharge rate of the light oil tank.

Viscosity Requirement: The viscosity of the fuel oil being pumped to the viscosity control valve must be low enough that an allowable minimum must be forwarded to the centrifuges to keep up with the flow rate demands of the diesel engine and atomizer.

CASE STUDY 5.1 (continued)

Economizer Selection

Boiler Selection: The economizer is used to increase the efficiency of the boiler and decrease the time needed for max steam production to occur by utilizing the atomizer exhaust gas to preheat the water in the boiler. The size of the economizer shall be determined by the size of the boiler since the economizer is supplementary to the boiler.

Atomizer Selection: The choice of atomizer dictates the flow rate and quality of heat to transfer via the exhaust gases following the combustion process that the economizer will utilize.

Condenser Selection

Steam Distribution: The amount of steam that the condenser will receive from the boiler will dictate its flow rate, size, and type needed to preserve as much heat in the water after the phase change process to maintain high efficiency.

Boiler Selection: The steam output properties from the boiler will dictate what type of condenser will be required to phase change the water back into liquid without overcooking it.

Hotwell Tank Selection

Boiler Selection: The volume of the boiler will dictate the size of the hotwell tank that is required. A smaller hotwell tank is desirable so less cooling will occur following condensation and more heat will be retained in the water as it is pumped back to the boiler.

Condenser Selection: The condenser limits the flow rate into the hotwell tank.

Feed Water Pump Selections

Boiler Selection: The circulation pump and main feed water pump control the volume of water present in the boiler. To regulate the temperature of the water in the boiler these two pumps need to work together to maintain a constant volume while steam leaves the boiler. The flow rate of steam leaving the boiler must be matched by the pumps feeding water to the boiler.

Economizer Selection: The economizer will require a certain flow rate of water from the circulation pump to raise the temperature of the water with the available heat from the exhaust gases.

Hotwell Tank Selection: The heat of the water pumped by the main feed water pump from the hotwell tank may cause damage to pumps not designed to handle it and that must be considered.

CASE STUDY 5.1 (continued)

Overall System Efficiency

Steam Distribution, Diesel Engine Requirement, Steam Heater Selections, Atomizer Selection, Economizer Selection, and Condenser Selection: To estimate the efficiency of the complete system, the amount of fuel oil harvested from the double bottom minus the amount used by the diesel engine through the atomizer must be known. The exhaust gas volume and temperature from the combustion process used by the economizer and boiler must be known. The boiler and economizer water volume must be known as well as the heat transfer from the atomizer exhaust into those two volumes. The amount of steam produced by the boiler and sent to the steam heaters and the condenser must be known.

Overall System Flow Rate

Steam Distribution, Diesel Engine Requirement, Boiler Selection, Steam Heater Selections, Atomizer Selection, Fuel Oil Pump Selections, Centrifuge Selection, Viscosity Requirement, Economizer Selection, Condenser Selection, and Feed Water Pump Selections: To estimate the flow rate of fuel oil the selections of all fuel oil components must be known because the velocity, pressure, and viscosity of the fuel/oil will vary as it moves away from the double bottom. The flow rate at each component will enable the flow rate of the fuel oil from the double bottom to the atomizer to be calculated. The water flow rate will be determined in a similar manner using the water components so that the flow rate of water from the boiler to the steam heaters will be calculated.

CASE STUDY 5.1 (continued)

Using aforementioned information, the task interaction matrix is developed as shown in Figure 5.23.

Task Interaction DSM	TASKS	Overall System Efficiency	Overall System Flow Rate:	Boiler Selection	Condenser Selection	Economizer Selection	Steam Distribution	Hotwell Tank Selection	Steam Heater Selection	Diesel Engine Requirement	Atomizer Selection	Centrifuge Selection	Settling Tank Selection	Fuel Oil Tank Selection	Fuel/Oil Pump Selections	Water Pump Selections	Viscosity Requirement
TASKS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Overall System Efficiency	1	1			X	X	X		X	X	X						
Overall System Flow Rate	2		2	X	X	X	X		X	X	X	X			X	X	X
Boiler Selection	3			3			X				X						
Condenser Selection	4			X	4		X										
Economizer Selection	5			X		5					X						
Steam Distribution	6						6										
Hotwell Tank Selection	7			X	X			7									
Steam Heater Selection	8			X			X		8								
Diesel Engine Requirement	9									9							
Atomizer Selection	10			X						X	10						
Centrifuge Selection	11											11			X		X
Settling Tank Selection	12									X			12	X			X
Fuel Oil Tank Selection	13									X	X			13			X
Fuel/Oil Pump Selections	14									X		X	X	X	14		
Water Pump Selections	15			X		X		X								15	
Viscosity Requirement	16									X	X	X	X	X	X		16

Figure 5.23: Process architecture DSM (identifies tasks interactions).

CASE STUDY 5.1 (continued)

Partitioned form of Figure 5.23 is shown in Figure 5.24.

Task Base DSM Partitioned / TASKS	TASKS	Steam Distribution 6	Diesel Engine Requirement 9	Boiler Selection 3	Atomizer Selection 10	Steam Heater Selection 8	Fuel Oil Pump Selections 14	Centrifuge Selection 11	Fuel Oil Tank Selection 13	Viscosity Requirement 16	Settling Tank Selection 12	Economizer Selection 5	Condenser Selection 4	Hotwell Tank Selection 7	Water Pump Selections 15	Overall System Efficiency 1	Overall System Flow Rate 2
Steam Distribution	6	6															
Diesel Engine Requirement	9		9														
Boiler Selection	3	X		3	X												
Atomizer Selection	10		X	X	10												
Steam Heater Selection	8	X		X		8											
Fuel Oil Pump Selections	14		X				14	X	X		X						
Centrifuge Selection	11						X	11		X							
Fuel Oil Tank Selection	13		X		X				13	X							
Viscosity Requirement	16		X		X		X	X	X	16	X						
Settling Tank Selection	12		X						X	X	12						
Economizer Selection	5			X	X							5					
Condenser Selection	4	X		X									4				
Hotwell Tank Selection	7			X									X	7			
Water Pump Selections	15			X								X		X	15		
Overall System Efficiency	1	X	X		X	X						X	X			1	
Overall System Flow Rate	2	X	X	X	X	X	X	X		X		X	X		X		2

Figure 5.24: Partitioned tasks interaction matrix with loops clustered.

CASE STUDY 5.1 (continued)

Partitioning Process

Empty rows of Steam Distribution and Diesel Engine Requirements are moved to the top rows of the matrix and their corresponding columns are moved to the two left-most columns. Empty columns of Overall System Efficiency and Overall System Flow Rate are shifted to the last two columns and their corresponding rows are moved to the bottom two rows. The empty rows signify those tasks do not require information to be completed. The empty columns signify those tasks do not generate any information used by other tasks.

After five partitioning attempts the number of feedback marks above the main diagonal was reduced to seven. Feedback marks indicate tasks dependent on information from other tasks that must be completed beforehand or an iterative process based on estimations must be used until the error criteria are satisfied. The following tasks have feedback marks: Boiler Selection, Atomizer Selection, Fuel Oil Pump Selection, Centrifuge Selection, fuel Oil Tank Selection, and Viscosity Requirement. For instance, the task Boiler Selection must occur after Steam Heater Selections and Atomizer Selection tasks have been completed. Alternatively, initial estimates for the steam heater and atomizer values may be used to select a boiler until the error criteria of the process reach an acceptable value.

Tasks without feedback marks possess forward marks below the main diagonal and can proceed without the completion of other tasks being required. While forward tasks do require information from other tasks to proceed, they can do so in sequence with each task as it is completed. For example, the Overall System Flow Rate can start as soon as information coming from any of its forward tasks becomes available and will be completed after the final proceeding task gives its information.

Minimizing feedback tasks is paramount to project efficiency since the greater number of iterations done will increase time usage and costs while waiting until other tasks are completed to start a task will do the same. The objective of partitioning is to minimize the number of feedback marks and thus reduce the number of feedback tasks. The development process interaction matrix is partitioned to achieve the least amount of feedback markers. A higher number of forwarding independent tasks will result in a more direct project progression and will reduce the time and costs required.

Partitioned Tasks Interaction Matrix Analysis: Tearing and Banding

Tasks 3 and 10 are interdependent or coupled therefore constant communication must occur between these two tasks. Multiple iterations may be required to complete both tasks after an initial assumption about one of them is made. The cluster loop of coupled tasks 14, 11, 13, 16, and 12 is the most complex and tedious part of the project. The highest number of iterations is going to occur with this cluster because of its size.

CASE STUDY 5.1 (continued)

Tearing-Case A: Tearing the feedback mark ("X" mark at the intersection of tasks 13 and 16 will be eliminated from the matrix) from task 13 will reduce the complexity and size of the cluster. But the number of tears should be kept to a minimum to avoid relying too much on initial guesses. Figure 5.25 shows the partitioned matrix after tearing. As seen from this figure, the complexity and size of the cluster reduced considerably compared with Figure 5.24.

Task Base DSM Partitioned After Tearing / TASKS	TASKS	Steam Distribution 6	Diesel Engine Requirement 9	Atomizer Selection 10	Boiler Selection 3	Fuel Oil Tank Selection 13	Fuel Oil Pump Selections 14	Centrifuge Selection 11	Settling Tank Selection 12	Viscosity Requirement 16	Condenser Selection 4	Economizer Selection 5	Hotwell Tank Selection 7	Steam Heater Selection 8	Water Pump Selections 15	Overall System Efficiency 1	Overall System Flow Rate 2
Steam Distribution	6	6															
Diesel Engine Requirement	9		9														
Atomizer Selection	10		X	10	X												
Boiler Selection	3	X		X	3												
Fuel Oil Tank Selection	13		X	X		13											
Fuel Oil Pump Selections	14		X			X	14	X	X								
Centrifuge Selection	11						X	11		X							
Settling Tank Selection	12		X			X			12	X							
Viscosity Requirement	16		X	X		X	X	X	X	16							
Condenser Selection	4	X			X						4						
Economizer Selection	5			X	X							5					
Hotwell Tank Selection	7				X						X		7				
Steam Heater Selection	8	X			X									8			
Water Pump Selections	15				X							X	X		15		
Overall System Efficiency	1	X	X	X							X	X		X		1	
Overall System Flow Rate	2	X	X	X	X		X	X		X	X	X		X	X		2

Figure 5.25: Partitioned tasks interaction matrix after tearing.

CASE STUDY 5.1 (continued)

Figure 5.26 shows the banding of partitioned matrix shown in Figure 5.25.

Task Base DSM Partitioned After Tearing	TASKS	Steam Distribution	Diesel Engine Requirement	Atomizer Selection	Boiler Selection	Fuel Oil Tank Selection	Fuel Oil Pump Selections	Centrifuge Selection	Settling Tank Selection	Viscosity Requirement	Condenser Selection	Economizer Selection	Hotwell Tank Selection	Steam Heater Selection	Water Pump Selections	Overall System Efficiency	Overall System Flow Rate
TASKS		6	9	10	3	13	14	11	12	16	4	5	7	8	15	1	2
Steam Distribution	6	6															
Diesel Engine Requirement	9		9														
Atomizer Selection	10		X	10	X												
Boiler Selection	3	X		X	3												
Fuel Oil Tank Selection	13		X	X		13											
Fuel Oil Pump Selections	14		X			X	14	X	X								
Centrifuge Selection	11						X	11		X							
Settling Tank Selection	12		X			X			12	X							
Viscosity Requirement	16		X	X		X	X	X	X	16							
Condenser Selection	4	X			X						4						
Economizer Selection	5			X	X							5					
Hotwell Tank Selection	7				X						X		7				
Steam Heater Selection	8	X			X									8			
Water Pump Selections	15				X							X	X		15		
Overall System Efficiency	1	X	X	X							X	X		X		1	
Overall System Flow Rate	2	X	X	X	X		X	X		X	X	X		X	X		2

Figure 5.26: Banding of partitioned matrix.

CASE STUDY 5.1 (continued)

Tearing-Case B: In this case, a different approach is used for tearing – removing the same feedback mark, "X", from the large cluster but keeping it in the matrix (not eliminating it from the matrix as we did in case A). This process may help to reduce the loss of information. Figure 5.27 shows the partitioned matrix after tearing. Following the tearing process, Task 13 can be completed before the tasks in the large cluster but the looping in the cluster is still problematic. It is clear that Task 16 is causing the most problems because it has the most feedback marks. An assumption that Task 16 should be ignored until the selection of all fuel oil components has been selected seems like the best solution. Task 16 is an assurance task with the purpose to double-check the component selections against the viscosity needed by connected components. Table 5.5 provides a potential algorithm to finish all tasks.

Task Base DSM Partitioned After Tearing		Steam Distribution	Diesel Engine Requirement	Boiler Selection	Atomizer Selection	Steam Heater Selection	Fuel Oil Tank Selection	Viscosity Requirement	Fuel Oil Pump Selections	Centrifuge Selection	Settling Tank Selection	Economizer Selection	Condenser Selection	Hotwell Tank Selection	Water Pump Selections	Overall System Efficiency	Overall System Flow Rate
TASKS		6	9	3	10	8	13	16	14	11	12	5	4	7	15	1	2
Steam Distribution	6	6															
Diesel Engine Requirement	9		9														
Boiler Selection	3	X		3	X												
Atomizer Selection	10		X	X	10												
Steam Heater Selection	8	X		X		8											
Fuel Oil Tank Selection	13		X		X		13	X									
Viscosity Requirement	16		X		X		X	16	X	X	X						
Fuel Oil Pump Selections	14		X				X		14	X	X						
Centrifuge Selection	11							X	X	11							
Settling Tank Selection	12		X				X	X			12						
Economizer Selection	5			X	X							5					
Condenser Selection	4	X		X									4				
Hotwell Tank Selection	7			X									X	7			
Water Pump Selections	15			X								X		X	15		
Overall System Efficiency	1	X	X		X	X						X	X			1	
Overall System Flow Rate	2	X	X	X	X	X	X	X		X		X	X		X		2

Figure 5.27: Partitioned tasks interaction matrix after tearing.

CASE STUDY 5.1 (continued)

Table 5.5: Suggested task completion sequence.

Executed	Task(s) #	Reasoning
1st	6 and 9	Do not require any input but affect twelve other tasks.
2nd	3	6 is completed. Iterate assuming that 8 will be the most efficient option and reiterate if the boiler meets the steam requirements.
3rd	10	9 is completed and the iteration result for 3 will be checked.
4th	8, 5, and 4	6, 3, and 10 have been completed.
5th	7	3 and 4 have been completed.
6th	15 and 1	6, 9, 3, 10, 8, 5, 4, and 7 have been completed.
7th	13	9 and 10 have been completed. Iterate assuming the steam heater will be capable of providing the correct exit viscosity to the fuel oil inside the light oil tank.
8th	14a and 12	14a being the selection of the booster pump since all components interacting with it have been selected. The choice of settling tank must reflect the size of the light oil tank which is known. Iterate assuming the steam heater will be capable of providing the correct exit viscosity to the fuel/oil inside the settling tank.
9th	14b and 11	14b being the selection of the centrifuges pump since that will influence the centrifuge type selected. Choose the cheapest type of centrifuge and assume that the inlet viscosity will be acceptable.
10th	14c and 16	14c being the selection of the transfer pump since it is the only pump left. Calculate the fuel oil viscosity at the inlet and outlet of all components to see if assumptions are acceptable or if another iteration is required.
Last	2	Requires the most inputs but is not required by other tasks.

CASE STUDY 5.1 (continued)

(c) **Organization Architecture DSM**

Once the task interactions and sequencing has been completed the research team(s) will be created to take responsibility for the tasks to be executed. The interactions between components and tasks are used to construct the team matrix. Clusters of team interactions can be used from meta-teams which are teams comprised of teams. The cluster relating Boiler Selection and Atomizer Selection shows a likely connection between the two meta-teams. Fuel oil and water component interactions can form two meta-teams quite easily. The nature of the interaction of the teams will be divided into daily, weekly, and once. The interaction between the teams will be information exchange about the project tasks.

Team Interaction Matrix Analysis

As shown in Figure 5.28, two meta-teams of water (blue) and Fuel Oil (orange) have been created and partitioned together. The partitioning of the groups together necessitated moving an empty row (Diesel Engine Requirements) away from the top of the matrix. The teams that receive information from an empty row only need to meet once to receive the information needed to start their task. Therefore, Steam Distribution and Diesel Engine Requirement teams will give their information to the teams that need it to begin their task at the beginning of the project. Overall System Efficiency and Overall System Flow Rate are dependent on final information from the other teams and will meet once with each upstream team at the completion of their upstream task. Teams within the same meta-team responsible for tasks that interact via component linkages will meet daily. For instance, Boiler Selection will meet Steam Heater Selections, Condenser Selection, Water Pump Selections, and Economizer Selection daily. Teams with tasks interacting with Viscosity Requirement will meet weekly to check if their iterations completed with assumptions about viscosity requirements are acceptable. Teams that interact across the two meta-teams (Atomizer Selection/Economizer Selection and Atomizer Selection/Boiler Selection) will meet weekly to share information. Quickly deciding on an atomizer and boiler will be the crucial step to project progression within each meta-team and project completion.

CASE STUDY 5.1 (Continued)

Team Base DSM / TASKS	TASKS	Steam Distribution	Boiler Selection	Steam Heater Selection	Condenser Selection	Water Pump Selections	Economizer Selection	Hotwell Tank Selection	Diesel Engine Requirement	Atomizer Selection	Fuel Oil Tank Selection	Fuel Oil Pump Selections	Viscosity Requirement	Centrifuge Selection	Settling Tank Selection	Overall System Efficiency	Overall System Flow Rate
		6	3	8	4	15	5	7	9	10	13	14	16	11	12	1	2
Steam Distribution	6	6															
Boiler Selection	3	O	3							W							
Steam Heater Selection	8	O	D	8													
Condenser Selection	4	O	D		4												
Water Pump Selections	15		D			15	D	D									
Economizer Selection	5		D				5			W							
Hotwell Tank Selection	7		W		D			7									
Diesel Engine Requirement	9								9								
Atomizer Selection	10		W						O	10							
Fuel Oil Tank Selection	13								O	D	13		W				
Fuel Oil Pump Selections	14								O		D	14		D	D		
Viscosity Requirement	16								O	W	W	W	16	W	W		
Centrifuge Selection	11											D	W	11			
Settling Tank Selection	12								O		W		W		12		
Overall System Efficiency	1	O		O	O		O		O	O						1	
Overall System Flow Rate	2	O	O	O	O	O	O		O	O		O	O	O			2

O → Once D → Daily W → Weekly

Figure 5.28: Organization (team) interactions matrix.

CASE STUDY 5.1 (continued)

(d) **Domain Mapping Matrix**

To show the interactions between two domains (task and person responsible) DMM (Domain Mapping Matrix) will be used. Rows will represent individuals responsible for tasks and columns will represent tasks. This will be used to select group leaders and dictate the minimum personnel required at meetings between teams. Group leaders selected will be done so by choosing individuals that have the most interactions. The Team DSM will be used as a starting point for the DMM construction however limiting the number of person/task interactions will modify it. As shown in Figure 5.29, each person will have two tasks, a primary task (indicated by a 1) and a secondary task (indicated by a 2). A primary task entails that person being the responsible party for that task's completion. A secondary task entails that person giving and receiving information with another person about their primary task. Secondary tasks pass information from person to person and then from team to team to complete each task and the project as a whole.

Domain Mapping Matrix Analysis

Boiler Selection and Atomizer Selection both have interactions with the most people. The two individuals with Boiler Selection and Atomizer Selection as their primary tasks will be the meta-team leaders (B and I). A certain amount of iterations will be unavoidable due to the coupled nature of Boiler Selection and Atomizer Selection. Person B and Person I will meet every week to share information from their teams. Viscosity Requirement, Overall System Flow Rate, and Fuel Oil Pump Selections have the second most people involved. These tasks interact with the most component selection tasks and require the second most information exchange other than Atomizer Selection and Boiler Selection. The teams selecting components directly connected will share information with the leader responsible for the task who will meet with the leader of the other component, this will occur daily as dictated by the Development Organization Interactions Matrix. Each week the leaders of each task team will meet with the meta-team leader and exchange information. This process shall continue until project completion.

CASE STUDY 5.1 (Continued)

DMM	TASKS	Steam Distribution	Boiler Selection	Steam Heater Selection	Condenser Selection	Water Pump Selections	Economizer Selection	Hotwell Tank Selection	Diesel Engine Requirement	Atomizer Selection	Fuel Oil Tank Selection	Fuel Oil Pump Selections	Viscosity Requirement	Centrifuge Selection	Settling Tank Selection	Overall System Efficiency	Overall System Flow Rate
Person		6	3	8	4	15	5	7	9	10	13	14	16	11	12	1	2
Team Member	A	1	2														
Team Member	B		1							2							
Team Member	C		2	1													
Team Member	D		2		1												
Team Member	E					1											2
Team Member	F		2				1										
Team Member	G					2		1									
Team Member	H								1	2							
Team Member	I		2							1							
Team Member	J										1		2				
Team Member	K											1					2
Team Member	L												1	2			
Team Member	M											2		1			
Team Member	N												2		1		
Team Member	O									2						1	
Team Member	P											2					1

1 → Primary Task 2 → Secondary Task

Figure 5.29: Domain Mapping Matrix (DMM).

CASE STUDY 5.1 (continued)

Note that, sequencing of the DSM rows and columns can have a different form such that the new DSM partition can be different than Figure 5.24. This does not mean that the previous partitioning is wrong – the solution is dependent on the sequencing of the DSM rows and columns. For example, Figure 5.30 is another partitioned solution for the same problem. When we check both partitioned Figure 5.24 and Figure 5.30, they both have the same original relationships shown in Figure 5.23. This means that both solutions are correct. However, Figure 5.24 shows a better solution with fewer "X" marks in the upper triangle.

Task Base DSM Partitioned	TASKS	Steam Distribution	Diesel Engine Requirement	Atomizer Selection	Boiler Selection	Centrifuge Selection	Fuel Oil Pump Selections	Settling Tank Selection	Fuel Oil Tank Selection	Viscosity Requirement	Condenser Selection	Economizer Selection	Hotwell Tank Selection	Steam Heater Selection	Water Pump Selections	Overall System Efficiency	Overall System Flow Rate
TASKS		6	9	10	3	11	14	12	13	16	4	5	7	8	15	1	2
Steam Distribution	6	6															
Diesel Engine Requirement	9		9														
Atomizer Selection	10		X	10	X												
Boiler Selection	3	X		X	3												
Centrifuge Selection	11					11	X			X							
Fuel Oil Pump Selections	14		X			X	14	X	X								
Settling Tank Selection	12		X					12	X	X							
Fuel Oil Tank Selection	13		X	X					13	X							
Viscosity Requirement	16		X	X		X	X	X	X	16							
Condenser Selection	4	X			X						4						
Economizer Selection	5			X	X							5					
Hotwell Tank Selection	7				X						X		7				
Steam Heater Selection	8	X			X									8			
Water Pump Selections	15				X							X	X		15		
Overall System Efficiency	1	X	X	X							X	X		X		1	
Overall System Flow Rate	2	X	X	X	X	X	X			X	X	X		X	X		2

Figure 5.30: New partitioned matrix.