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THE SYSTEM OVERLAP MATRIX – A METHOD AND TOOL FOR THE SYSTEMATIC IDENTIFICATION OF COMMONALITY OPPORTUNITIES IN COMPLEX TECHNICAL SYSTEMS

Wilfried K. Hofstetter[1], Paul D. Wooster[2], Olivier L. de Weck[3], Edward F. Crawley[4]

[1]PhD candidate, Department of Aeronautics and Astronautics, MIT
[2]Research scientist, Department of Aeronautics and Astronautics, MIT
[3]Associate Professor of Aeronautics and Astronautics and Engineering Systems, MIT
[4]Professor of Aeronautics and Astronautics and Engineering Systems, MIT

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1 INTRODUCTION

The use of common elements across systems or products that are part of the same program or portfolio has generally been identified as a way to increase affordability and decrease risk of the development and operation of the portfolio [1, 2, 3]. Given the potentially high impact, it is desirable to identify opportunities for commonality and assess associated benefits and draw-backs as early as possible in the design of the portfolio (maximum design freedom). The work presented here is therefore focused on the early stages of system design, often called system architecting or conceptual design.

2 EXISTING METHODS FOR IDENTIFYING COMMONALITY

In the most general sense, commonality is defined as the "possession of shared features and attributes across different systems" [4]; these could include: specific functions, the system architecture, specific operational characteristics, specific technologies, and specific design parameters of the system. A number of methods for the systematic identification of commonality opportunities would have been proposed; they can be broadly grouped into two sets:

- Function-based methods [1, 4, 5]: opportunities for commonality are identified based on similarities in the function structures of the associated systems. Conceptual design solutions are then created by assigning common functions to common modules.
- Methods based on similarities in engineering model parameters: these include optimization-based platform analysis approaches such as described in [2, 8], as well as DSM-based approaches [7]

Methods based on function structures do not take into account similarities or differences in architectural concepts, technology choices, or operational requirements, and are therefore not sufficiently detailed to identify commonality for complex systems. Methods based on engineering models can be very effective at identifying commonality opportunities for complex systems; the required detailed models are, however, usually based on a specific concept and are therefore not available during conceptual design. This indicates the need for new methods for the systematic identification of commonality opportunities in complex systems during the architecting phase; the System Overlap Matrix is proposed as one such method.

3 THE SYSTEM OVERLAP MATRIX

The SOM method is part of an integrated framework for architecting and commonality analysis of portfolios of complex systems shown in Figure 1 [9]. As the SOM is used during the identification of commonality options, its inputs are a set of interesting architectures / concepts for each of the systems in the portfolio, which have been identified in the analysis of individual system architectures. Output is a set of technically feasible commonality opportunities between systems for evaluation with regard to benefits and penalties of commonality (see Figure 1).

The SOM itself captures 3 key system characteristics: functionality (i.e. functional requirements), operational building blocks (i.e. operational requirements), and technology choices associated with the functions. Figure 2 shows an example SOM for a spacecraft (excerpt); the functions and associated technology choices are arrayed vertically to the left, essentially forming a vertically oriented

Morphological Matrix [5]. Operational building blocks with their environmental subcategories are arrayed along the top. As the number of functions and associated technology choices does not necessarily equal the number of operational building blocks, the SOM is generally rectangular. A SOM constructed like this can capture different concepts for one system in the portfolio. In order to be useful for commonality identification between concepts for different systems in the portfolio, the matrix has to be able to capture concepts of all systems in the portfolio. To that end, the union of the functions, technology choices, and operational building blocks from all systems in the portfolios is used. Concepts are marked in the SOM using “1” if a particular function / operations combination is required, and “0” otherwise. Figure 3 shows the result of overlaying SOMs for concepts of two different systems in the same portfolio; the overlay is accomplished by adding the entries in the matrices for the individual systems. By successively overlaying matrices for pairs of system concepts, an analysis of commonality opportunities can be carried out in an automated fashion.

The SOM can only provide insight into commonality opportunities related to requirements (functional and operational) and technology choices associated with functionality; in order to identify opportunities for architectural and design commonality, information about the internal connectivity of the systems in question is required. We propose the use of component-component DSMs coupled to the SOM via component-functionality and component-operations matrices (see Figure 4) [11]. Similarity in the number of components, component connectivity, as well as functionality and operations assigned to components is a strong indication of opportunities for architectural and design commonality between systems.

4 CONCLUSION

A new method has been developed using a matrix which captures the union of all functions, associated technologies, and operational building blocks for all systems in a system portfolio. All interesting concepts identified for the systems in the portfolio can be mapped out in the matrix. The matrix can be used in an automated fashion to identify opportunities for commonality in functionality, associated technologies, and operations between concepts for different systems in the portfolio. When coupled with a component-component DSM to allow for the assessment of system-internal connectivity, it can further provide a tool for identification of opportunities for architectural and design commonality.

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Contact: Wilfried K. Hofstetter
Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
77 Massachusetts Avenue
Cambridge, MA, 02142, USA
wk_hof@mit.edu

APPENDIX

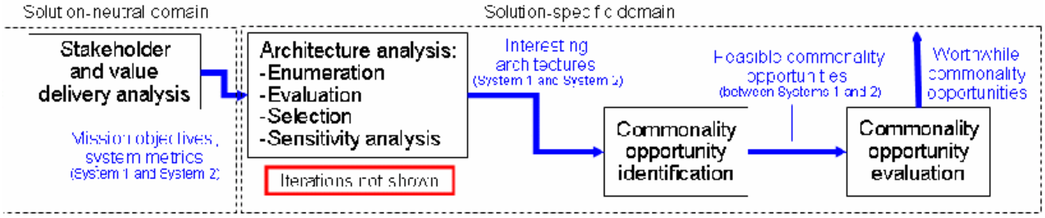

Figure 1: Systems architecting and commonality analysis framework [9] (shown for 2 systems)

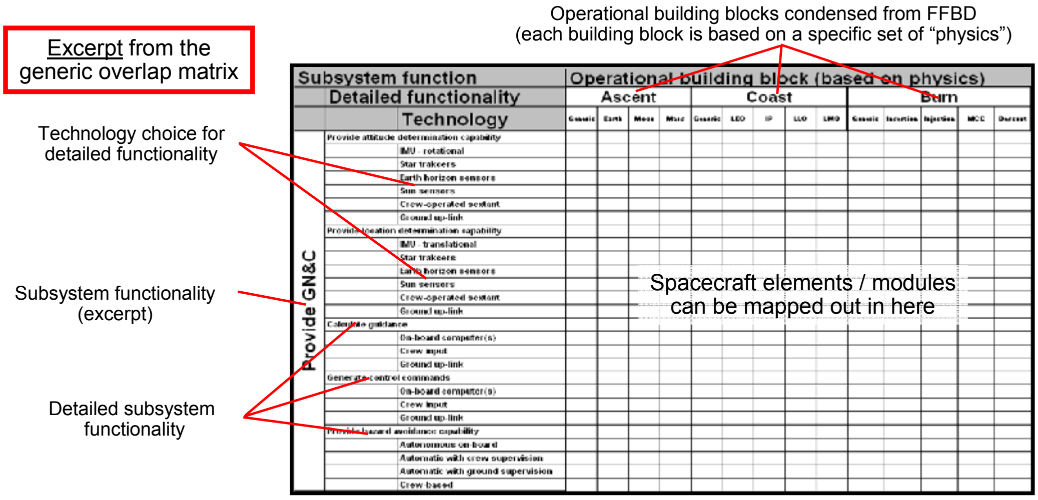

Figure 2: Excerpt from the System Overlap Matrix template for a spacecraft

Subsystem function / Detailed functionality / Technology	Ascent: Generic	Ascent: Earth	Ascent: Moon	Ascent: Mars	Coast: Generic	Coast: LEO	Coast: IP	Coast: LLO	Coast: LMO	Burn: Generic	Burn: Insertion	Burn: Injection	Burn: MCC	Burn: Descent
Provide GN&C														
Provide attitude determination capability	0	1	1	0	0	1	1	2	0	0	2	2	2	1
IMU - rotational	0	1	1	0	0	1	1	2	0	0	2	2	2	1
Star trakcers	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Earth horizon sensors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sun sensors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crew-operated sextant	0	0	0	0	0	1	1	2	0	0	1	1	1	0
Ground up link	0	1	0	0	0	1	1	1	0	0	0	0	0	0
Provide location determination capability	0	1	1	0	0	1	1	2	0	0	2	2	2	1
IMU - translational	0	1	1	0	0	1	1	2	0	0	2	2	2	1
Star trakcers	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Earth horizon sensors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sun sensors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crew-operated sextant	0	0	0	0	0	1	1	2	0	0	1	1	1	0
Ground up-link	0	0	0	0	0	1	1	1	0	0	0	0	0	0
Calculate guidance	0	1	1	0	0	1	1	1	0	0	2	2	2	1
On-board computer(s)	0	1	1	0	0	1	1	1	0	0	2	2	2	1
Crew input	0	0	1	0	0	1	1	1	0	0	2	2	2	1
Ground up link	0	1	0	0	0	1	1	1	0	0	0	0	0	0

Figure 3: Overlap of SOM for CEV Crew Module and LSAM ascent stage concepts [10]. Analysis is based on adding the entries from matrices for the individual systems; fields with a 2 indicate overlap. Further overlap: functionality (blue), operations (green), technology (yellow)

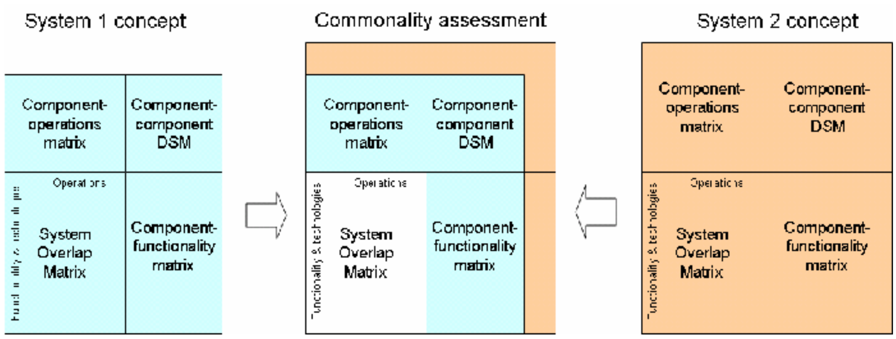

Figure 4: Coupling of SOM to component-component DSM via component-operations / functionality matrices for identification of opportunities for architectural and design commonality

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Olivier de Weck, Edward Crawley

Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
Cambridge, MA, USA

Capitalize on Complexity
In cooperation with BMW Group

Presentation Overview

- Introduction & motivation
- The System Overlap Matrix (SOM)
- Commonality analysis using the SOM
- SOM and DSM
- Summary

Introduction and Motivation (1)

- The development and operation of portfolios of complex systems is becoming commonplace in many areas including:
  - Communications and transportation infrastructure
  - Defense systems, transportation systems
  - Space exploration programs (human as well as robotic)
- These portfolios may include systems that are under development and that are planned for future development, as well as legacy systems
- Example for such a complex systems portfolio: NASA Constellation program with its associated launch vehicles and spacecraft

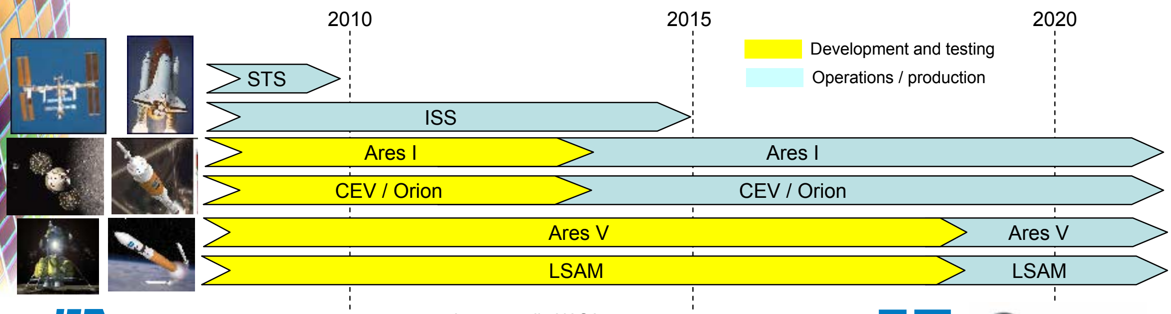
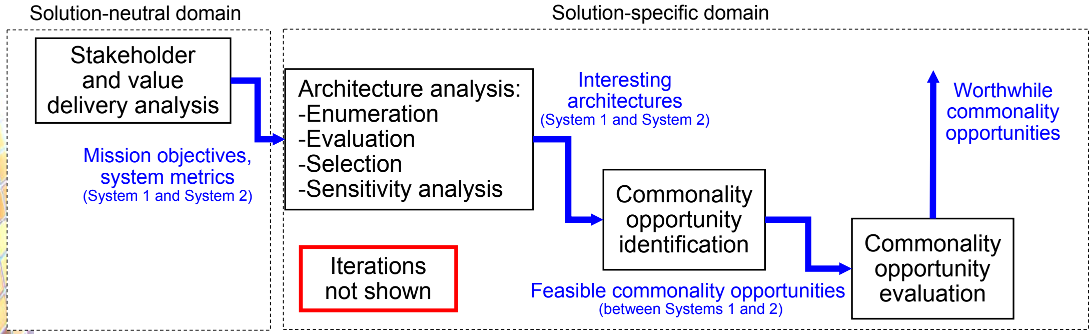


Image credit: NASA

Introduction and Motivation (2)

- Commonality between systems in this portfolio (defined as possession of shared features or attributes) may offer the following advantages:
  - Reduced lifecycle development cost and risk for the portfolio
  - Reduced lifecycle operations cost and risk for the portfolio
  - Accelerated development schedule
  - These benefits need to be weighed against possible cost and risk penalties on the systems in the portfolio developed first
- Opportunities for commonality should be identified when maximum design freedom is available, i.e. during system architecting
- Two major groups of methods exist to analyze commonality opportunities for systems:
  - Manual comparison of function structures (suitable for low-complexity systems, but less so for complex systems)
  - Methods based on detailed engineering models (require concept which is developed during systems architecting)
- This indicates that new methods are needed for system architecting

Framework for Commonality Analysis During Conceptual Design



- A 4-step framework is proposed for the systematic analysis of commonality opportunities during the systems architecting phase
- Analysis of stakeholder needs and system architectures to address these needs precedes commonality analysis
  - Analysis carried out without consideration for commonality
- Commonality analysis consists of identifying opportunities for commonality and subsequent quantitative benefit / penalty evaluation

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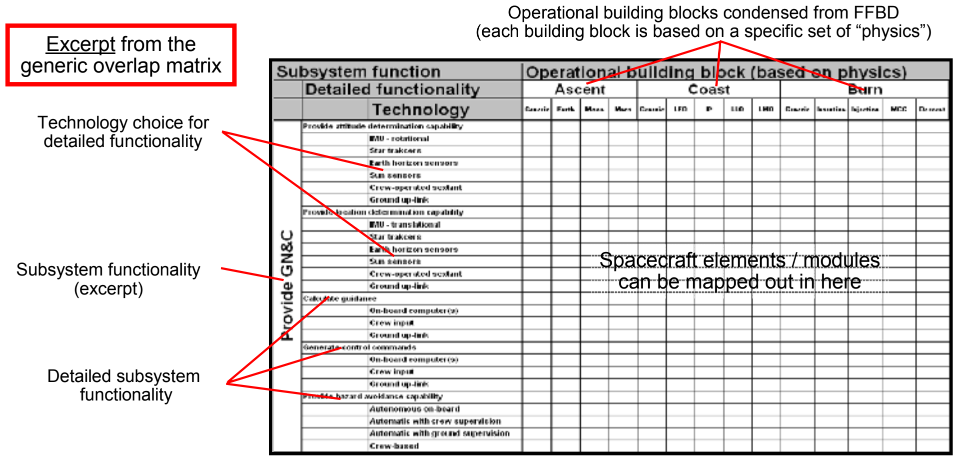
Overview of the System Overlap Matrix (SOM)



- Internal functions and associated technology choices are arranged along the vertical (one-dimensional Morphological Matrix)
- Operational building blocks are arranged along the horizontal
- In order to be able to capture any system concept, functions, technologies and operations need to be the unions of all corresponding sets in the portfolio

Application Example (1) – CEV Crew Module GN&C Subsystem

Subsystem functionality	Detailed functionality	Technology	Operational environment: Ascent				Coast					Burn				
			Generic	Earth	Moon	Mars	Generic	LEO	IP	LLO	LMO	Generic	Insertion	Injection	MCC	Descent
Provide GN&C	Provide attitude determination capability			1				1	1	1			1	1	1	
		IMU - rotational		1				1	1	1			1	1	1	
		Star trackers														
		Earth horizon sensors														
		Sun sensors														
		Crew-operated sextant						1	1	1			1	1	1	
		Ground up-link		1				1	1	1						
	Provide location determination capability			1				1	1	1			1	1	1	
		IMU - translational		1				1	1	1			1	1	1	
		Star trackers														
		Earth horizon sensors														
		Sun sensors														
		Crew-operated sextant						1	1	1			1	1	1	
		Ground up link						1	1	1						
	Calculate guidance			1				1	1	1			1	1	1	
		On-board computer(s)		1				1	1	1			1	1	1	
		Crew input						1	1	1			1	1	1	
		Ground up-link		1				1	1	1						
	Generate control commands			1				1	1	1			1	1	1	
		On-board computer(s)		1				1	1	1			1	1	1	
		Crew input		1				1	1	1			1	1	1	
		Ground up-link														
	Provide hazard avoidance capability															
		Autonomous on-board														
		Automatic with crew supervision														
		Automatic with ground supervision														
		Crew-based														

Application Example (2) – LSAM Ascent Stage GN&C Subsystem

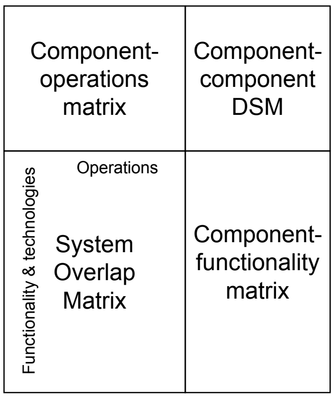
Subsystem functionality	Detailed functionality	Technology	Operational environment: Ascent				Coast					Burn				
			Generic	Earth	Moon	Mars	Generic	LEO	IP	LLO	LMO	Generic	Insertion	Injection	MCC	Descent
Provide GN&C	Provide attitude determination capability				1					1			1	1	1	1
		IMU - rotational			1					1			1	1	1	1
		Star trackers														
		Earth horizon sensors														
		Sun sensors														
		Crew-operated sextant								1						
		Ground up-link														
	Provide location determination capability				1					1			1	1	1	1
		IMU - translational			1					1			1	1	1	1
		Star trackers														
		Earth horizon sensors														
		Sun sensors														
		Crew-operated sextant								1						
		Ground up link														
	Calculate guidance				1								1	1	1	1
		On-board computer(s)			1								1	1	1	1
		Crew input			1								1	1	1	1
		Ground up-link														
	Generate control commands				1								1	1	1	1
		On-board computer(s)			1								1	1	1	1
		Crew input			1								1	1	1	1
		Ground up-link														
	Provide hazard avoidance capability															
		Autonomous on-board														
		Automatic with crew supervision														
		Automatic with ground supervision														
		Crew-based														

Application Example (3) – CEV CM and LSAM Ascent Stage Overlap

Subsystem function	Detailed functionality	Technology	Operational building blocks: Ascent				Coast					Burn				
			Generic	Earth	Moon	Mars	Generic	LEO	IP	LLO	LMO	Generic	Insertion	Injection	MCC	Descent
Provide GN&C	Provide attitude determination capability		0	1	1	0	0	1	1	2	0	0	2	2	2	1
		IMU - rotational	0	1	1	0	0	1	1	2	0	0	2	2	2	1
		Star trackers	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Earth horizon sensors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Sun sensors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Crew-operated sextant	0	0	0	0	0	1	1	2	0	0	1	1	1	0
		Ground up link	0	1	0	0	0	1	1	1	0	0	0	0	0	0
	Provide location determination capability		0	1	1	0	0	1	1	2	0	0	2	2	2	1
		IMU - translational	0	1	1	0	0	1	1	2	0	0	2	2	2	1
		Star trackers	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Earth horizon sensors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Sun sensors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Crew-operated sextant	0	0	0	0	0	1	1	2	0	0	1	1	1	0
		Ground up link	0	0	0	0	0	1	1	1	0	0	0	0	0	0
	Calculate guidance		0	1	1	0	0	1	1	1	0	0	2	2	2	1
		On-board computer(s)	0	1	1	0	0	1	1	1	0	0	2	2	2	1
		Crew input	0	0	1	0	0	1	1	1	0	0	2	2	2	1
		Ground up-link	0	1	0	0	0	1	1	1	0	0	0	0	0	0
	Generate control commands		0	1	1	0	0	1	1	1	0	0	2	2	2	1
		On-board computer(s)	0	1	1	0	0	1	1	1	0	0	2	2	2	1
		Crew input	0	1	1	0	0	1	1	1	0	0	2	2	2	1
		Ground up-link	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Provide hazard avoidance capability		0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Autonomous on-board	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Automatic with crew supervision	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Automatic with ground supervision	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Crew-based	0	0	0	0	0	0	0	0	0	0	0	0	0	0

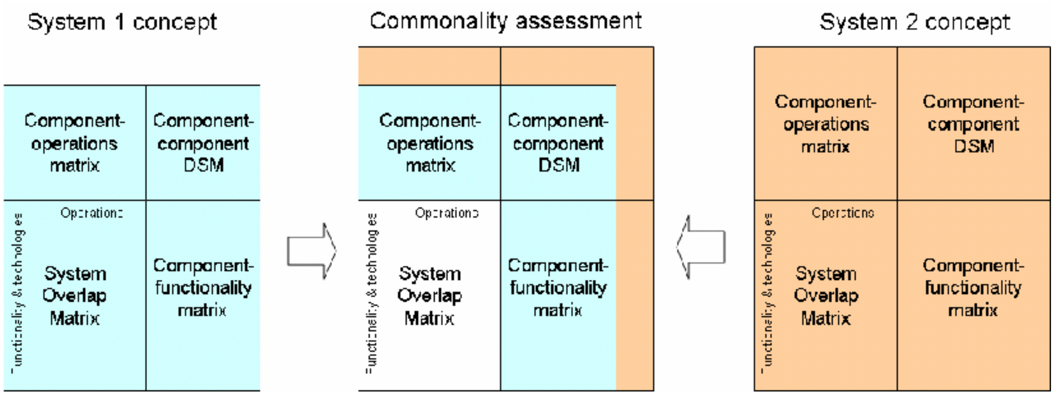
Complete overlap (identity)
Technology overlap
Operational overlap
Functional overlap

SOM and DSM (1)



- The System Overlap Matrix does not capture internal connectivity of the systems in the portfolio
- This means that it cannot be used to identify opportunities for design and architectural commonality
- Internal connectivity can be effectively analyzed using component-component DSMs
- By coupling a component-component DSM to the SOM (via component-function and component-operations matrices), integrated commonality analysis is possible

SOM and DSM (2)



- Overlap could be carried out in the same way as for the SOM
- Clustering of the DSM with subsequent comparison of the order of functions in the SOM can also be used for identification of common sets of closely interrelated components

Summary

- The development and operation of portfolios of complex systems including legacy systems, systems under development, and planned future systems is commonplace in many areas
- Commonality can offer significant life-cycle advantages with respect to cost, risk, and schedule, especially when considered early in design
- The System Overlap Matrix (SOM) is a method and tool for the identification of opportunities for functional, operational, and technology commonality between complex systems
- The SOM is intended for application as part of a framework for architecture and commonality analysis during early design
- When coupled with a component-component DSM, the SOM can also be used for identification of opportunities for architectural and design commonality
- Opportunities for future work include more detailed investigation of DSM clustering on commonality analysis and integration of the SOM with system architecture analysis for automated end-to-end analysis

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