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Methodology for Evaluating a Digital Architecture in Terms of Systems Engineering Lifecycle Using Variables in the Context of Digital Twin Testbed

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INCOSE International Symposium 2025 | Ottawa, Canada

Today's Agenda

Overview:

- Lifecycle of the System
- System Architecture
- Digital Twin Testbed
- Design Structure Matrix (DSM)

Architecture Evaluation

- DSM Analysis
- Evaluation of Criticality
- Digital Twin Testbed
- Pearson Correlation

Conclusions

Future research

Concepts for the Evaluation of the Digital Architecture

Lifecycle of the System → **System Architecture** → **Digital Twin Testbed** → **Design Structure Matrix (DSM)**

Lifecycle of the System

A system life cycle is the evolution of a system, product, service, or enterprise from conception through retirement. Systems engineering applies across a life cycle, involving activities such as stakeholder needs definition, requirements development, design, integration, verification, validation, operation, and disposal

INCOSE Systems Engineering Handbook, 5th Edition (2015) International Council on Systems Engineering (INCOSE

System Architecture

System architecture addresses the architecture of a system.

System architecture is an architecture concerning a system entity and its system elements

IISO//IEC/IEEE 42024- Enterprise, systems and software — Architecture fundamentals

Digital Twin Testbed

MBSE testbed construct provides a modeling, simulation, and integration environment for developing and evaluating digital twins.

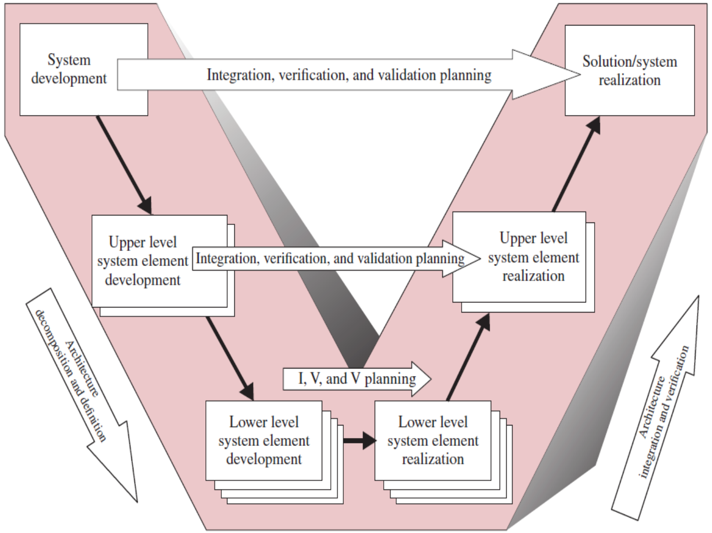
Madni, A. M. (2021). MBSE testbed for rapid, cost-effective prototyping and evaluation of system modeling approaches. Applied Sciences, 11(5), 2321

Design Structure Matrix (DSM)

The DSM is a network modeling tool used to represent the elements comprising a system and their interactions, thereby highlighting the system's architecture (or designed structure).

Eppinger, S. D., & Browning, T. R. (2012). Design Structure Matrix Methods and Applications. In Design Structure Matrix Methods and Applications. The MIT Press. https://doi.org/10.7551/mitpress/8896.001.0001

Different lifecycles with same goal with the support of applications



Vee model. Derived from Forsberg et al. (2005), Figure 7.10. Reprinted with permission from Kevin Forsberg. All other rights reserved.

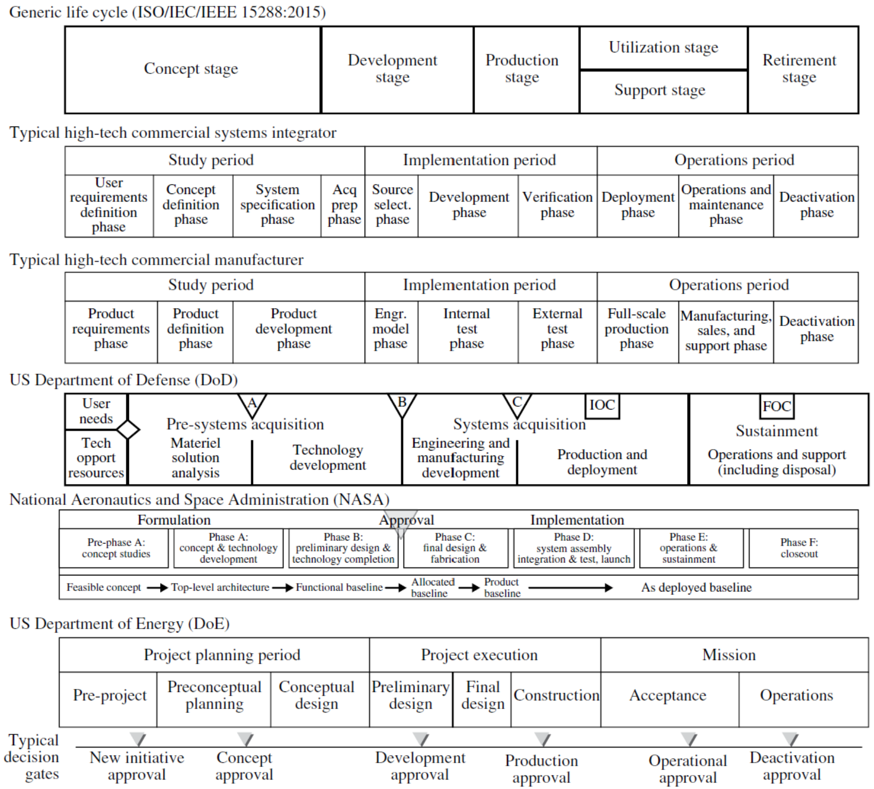


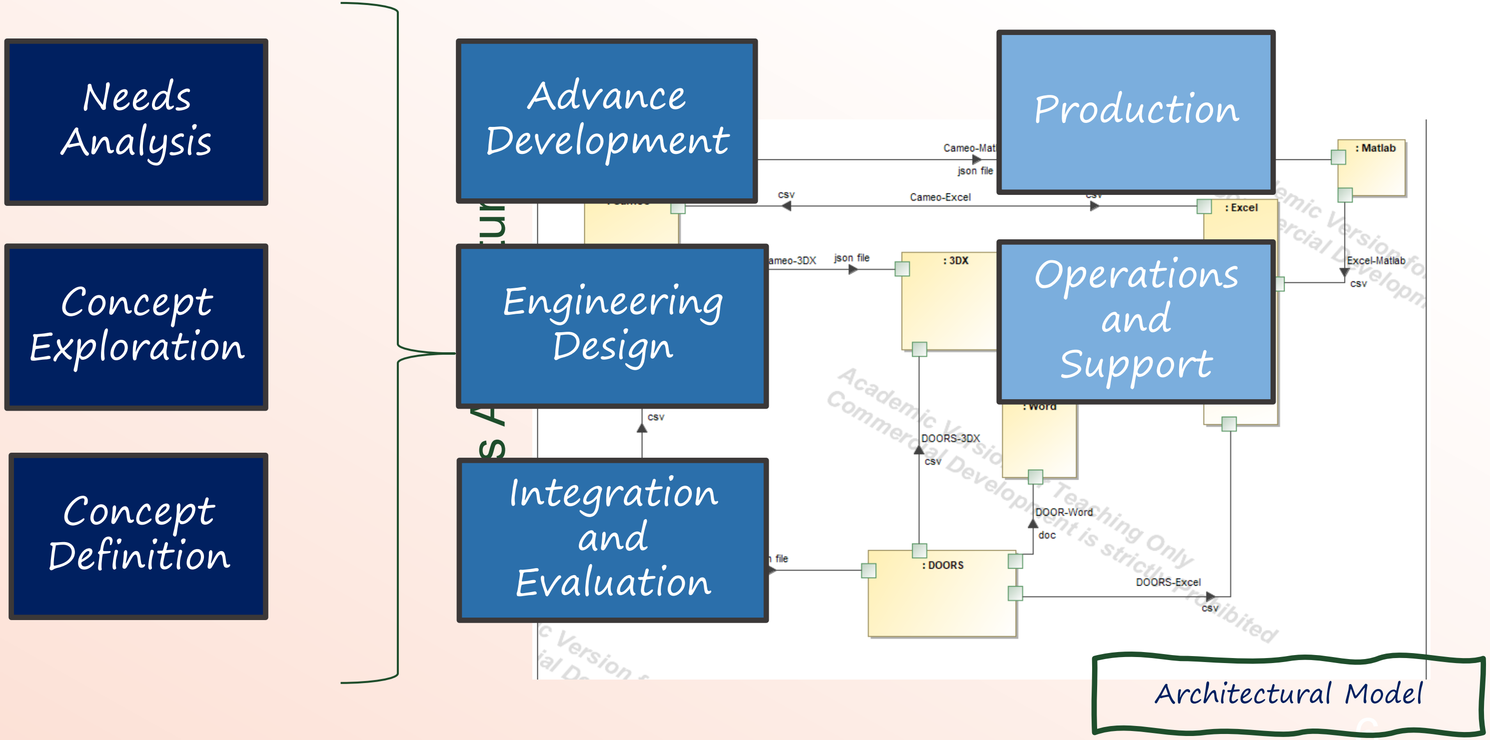
FIGURE 3.3 Comparisons of life cycle models. Derived from Forsberg et al. (2005), Figure 7.2. Reprinted with permission from Kevin Forsberg. All other rights reserved.

International Council on Systems Engineering (INCOSE). (2015). *INCOSE Systems Engineering Handbook: A guide for system life cycle processes and activities* (4th ed.). Wiley.

Architecture Evaluation

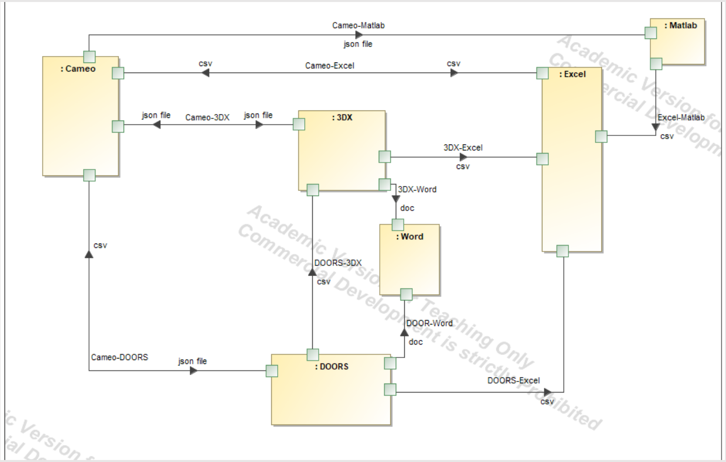
Evaluation of the Digital Architecture

Systems Lifecycle Model by William Rouse and Andrew P. Sage



Views of the Architecture

Architectural Model

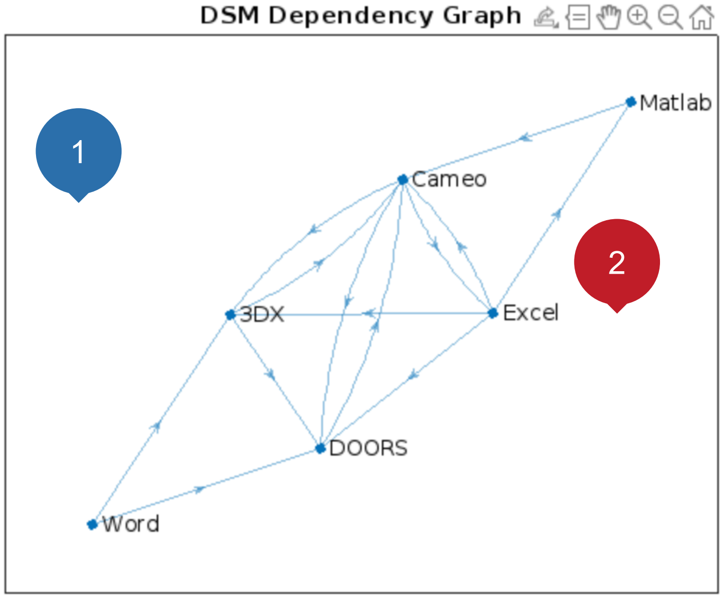


Mathematical Model

DSM =

	Cameo	Matlab	DOORS	Excel	Word	3DX
Cameo	0	1	1	1	0	1
Matlab	0	0	0	1	0	0
DOORS	1	0	0	1	1	1
Excel	1	0	0	0	0	0
Word	0	0	1	0	0	1
3DX	1	0	0	1	1	0

DSM Analysis



1 DSM Analysis

Graph clustering:

Emphasizes connectivity and mutual influence.

2

Clustering Results

Emphasizes connectivity and mutual influence.

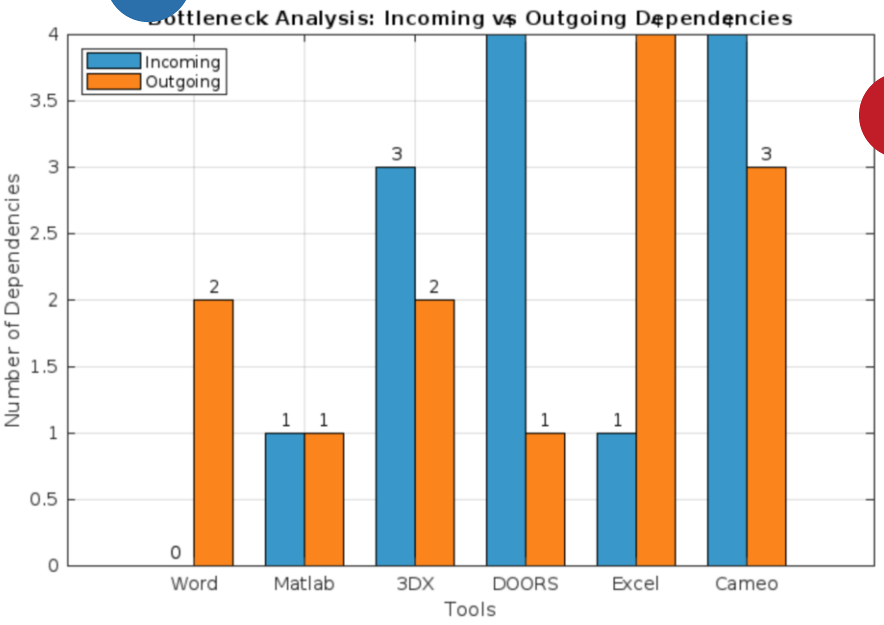
Cluster 1: Word

Cluster 2: MATLAB, 3DX, DOORS, Excel, Cameo

.

DSM Analysis

3



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3 Incoming and outgoing dependencies

Graph clustering:

Emphasizes connectivity and mutual influence.

4 Dependencies

Incoming Dependencies: tools that rely on other tools to receive input.

Upstream dependency

Outgoing dependencies: source of dependency for other tools.

This might be a source data critical path

Evaluation of Criticality

5

Node	In_Degree	Out_Degree	Centrality	PageRank
{'Word' }	0	2	0	0.025
{'Matlab'}	1	1	0	0.053013
{'3DX' }	3	2	1.5	0.17042
{'DOORS' }	4	1	1.5	0.24286
{'Excel' }	1	4	4	0.13178
{'Cameo' }	4	3	10	0.37692

Out_Degree= Applications provide support to others MS Excel

Centrality: critical components is Cameo Systems Modeler

In_Degree= Applications that depends on others. Cameo Systems Modeler and DOORS

5 Customer Data Analysis

In_Degree: Highly dependent components

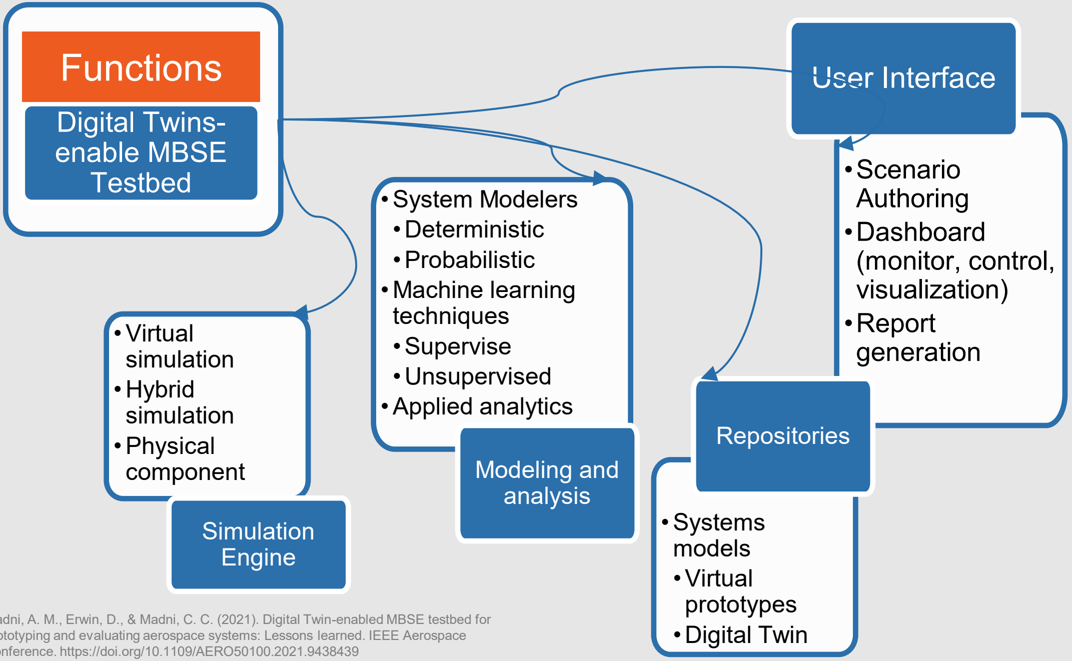
Out_Degree : Components that depend on others.

Centrality: critical components that act as bridge

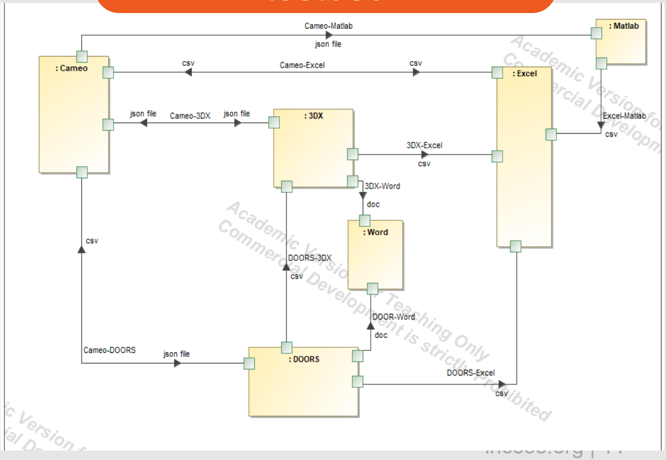
PageRank: applications with wide influence and indirect importance

Digital Twin Testbed

The MBSE testbed is intended to support researchers engaged in modeling, analyses, and testing of complex systems and system-of-systems primarily in aerospace and automotive domains.



Architecture supporting the Functions of the testbed



Madni, A. M., Erwin, D., & Madni, C. C. (2021). Digital Twin-enabled MBSE testbed for prototyping and evaluating aerospace systems: Lessons learned. IEEE Aerospace Conference. https://doi.org/10.1109/AERO50100.2021.9438439

Digital Twin Testbed - Criticality

Connectors	Scenario-Authoring	Dashboarding	Reporting	Souce Application	Target Application
Cameo-MATLAB	✓	✗	✓	Cameo	MATLAB
Cameo-DOORS	✗	✓	✓	Cameo	DOORS
Cameo-Excel	✗	✗	✓	Cameo	Excel
DOORS-Word	✗	✗	✓	DOORS	Word
DOORS-Excel	✗	✗	✓	DOORS	Excel
DOORS-Cameo	✓	✓	✓	DOORS	Cameo
Excel-Cameo	✓	✗	✗	Excel	Cameo
MATLAB-Excel	✗	✗	✗	MATLAB	Excel
Cameo -3DX	✓	✓	✓	Cameo	3DX
3DX- Cameo	✓	✓	✓	3DX	Cameo
DOORS-3DX	✓	✓	✓	DOORS	3DX
3DX-Excel	✗	✗	✓	3DX	Excel
3DX-Word	✗	✗	✓	3DX	Word

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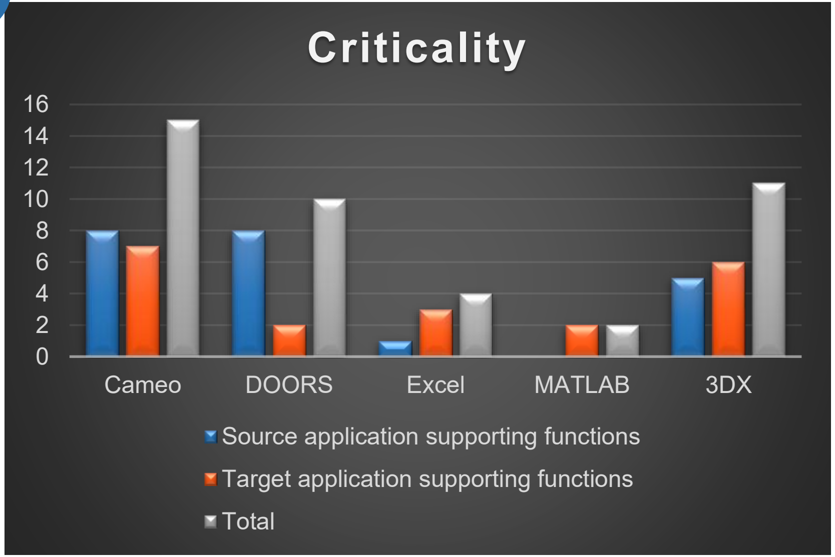

- Cameo is the application that has the biggest impact in this architecture.
- 3DX is a bit more prominent role than DOORS. DOORS has an impact as source application.
- Excel's primary function is centered around supporting reporting activities.
- Word and MATLAB role is limited. It can be interpreted as supporting roles within the architecture.

The Pearson correlation coefficient

The Pearson correlation coefficient measures the strength of the linear association between two variables.

- High correlation implies synergy or reuse between phases .
- Low or negative correlation can imply that the variables (tools) are isolated or exhibit modularity.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \overline{y)}}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}.\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}.}$$

$x \text{ and } y \text{ are vector}$

$\bar{x} \text{ and } \bar{y} \text{ are the means}$

$n \text{ is the number of applications}$

Correlation

Pearson correlation

	Scenario-Authoring	Dashboarding	Reporting
Scenario-Authoring	1.000	0.537	-0.033
Dashboarding	0.537	1.000	0.337
Reporting	-0.033	0.337	1.000

Moderate positive correlation:
0.53→ Scenario-Authoring and Dashboarding. The two activities mostly occur together.
Weak Correlation:
0.337 → Reporting- Dashboarding.
Very Weak correlation
-0.033→ Scenario-Authoring vs. Reporting. Functions are decoupled. This reflects proper separation

Conclusions

- **Digital architectures can be viewed as mathematical models and quantitative evaluations can be performed.**
- **DSM helps to understand the architecture based on its components and connections.**
- DSM supports functional analysis of the applications
- DSM exposes behavior of applications as clusters, bottlenecks, critical applications, isolated applications, etc.

Future research:

- AI – creating a strong architecture, reaching meaningful data, identifying cross dependencies, etc.
- Cost analysis.