Design Structure Matrix for Product Architecture Models

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June 8, 2021

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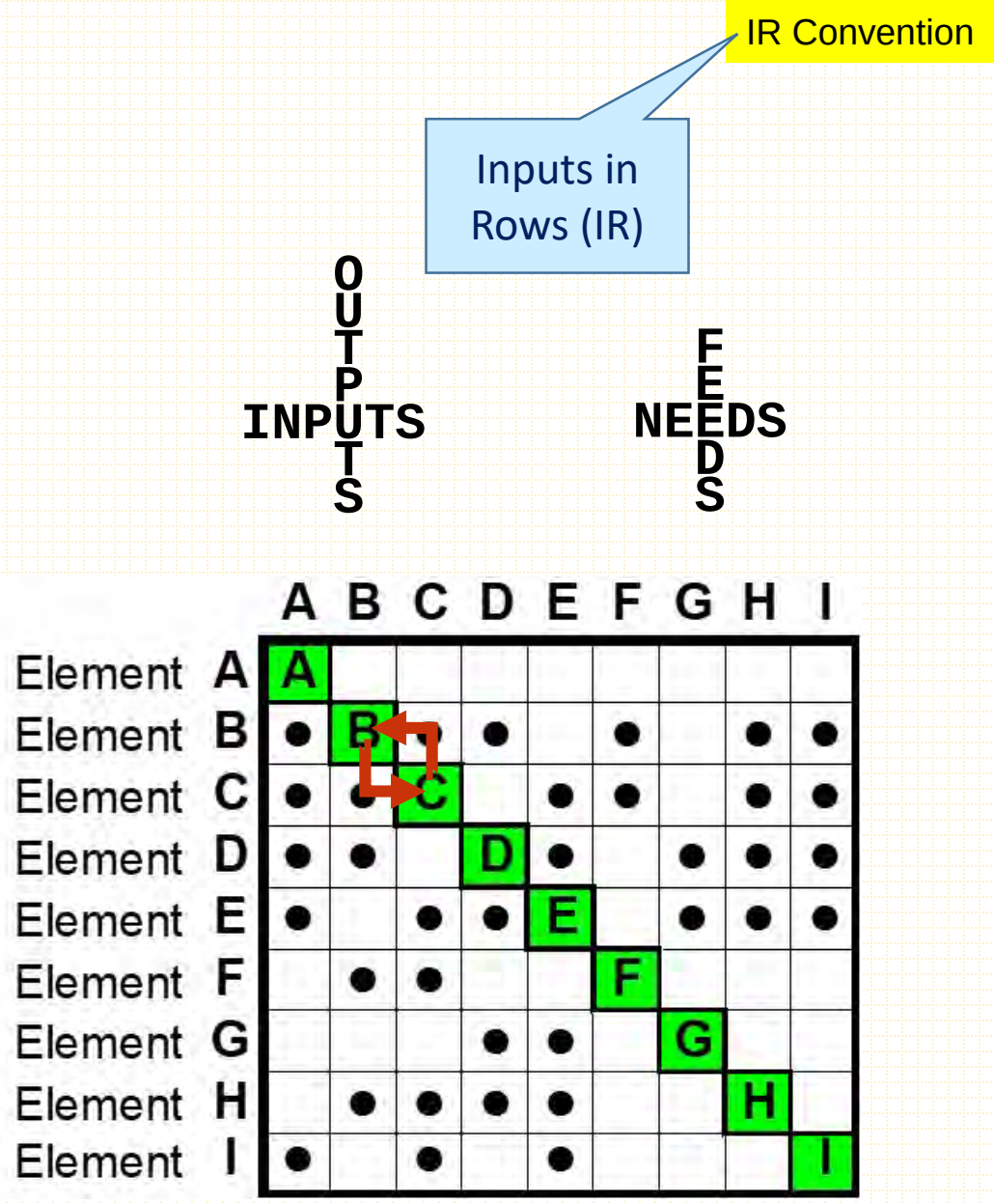
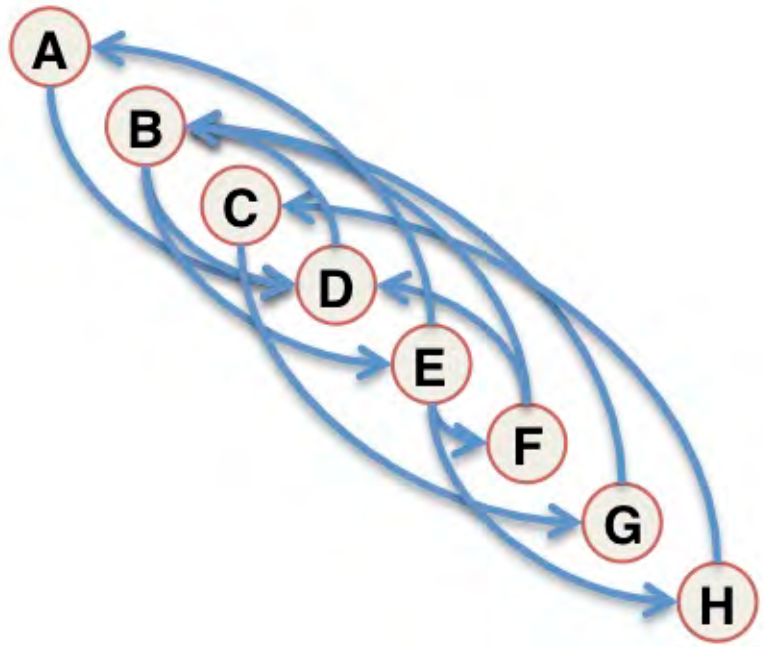
What Is the Matrix? (Basic)

- A square matrix showing relationships among elements
- Shaded, diagonal squares represent the elements
- Off-diagonal marks represent a relationship
  - Read down a column to see where the element provides something
  - Read across a row to see where the element receives something
- Capable of representing directional (asymmetric) relationships



DSM ←→ Node-Link Diagram

	A	B	C	D	E	F	G	H
A	A				X			
B		B		X		X	X	
C			C					X
D	X	X		D		X		
E		X			E			
F					X	F		
G			X				G	
H					X			H



Complexity Is a Challenge…

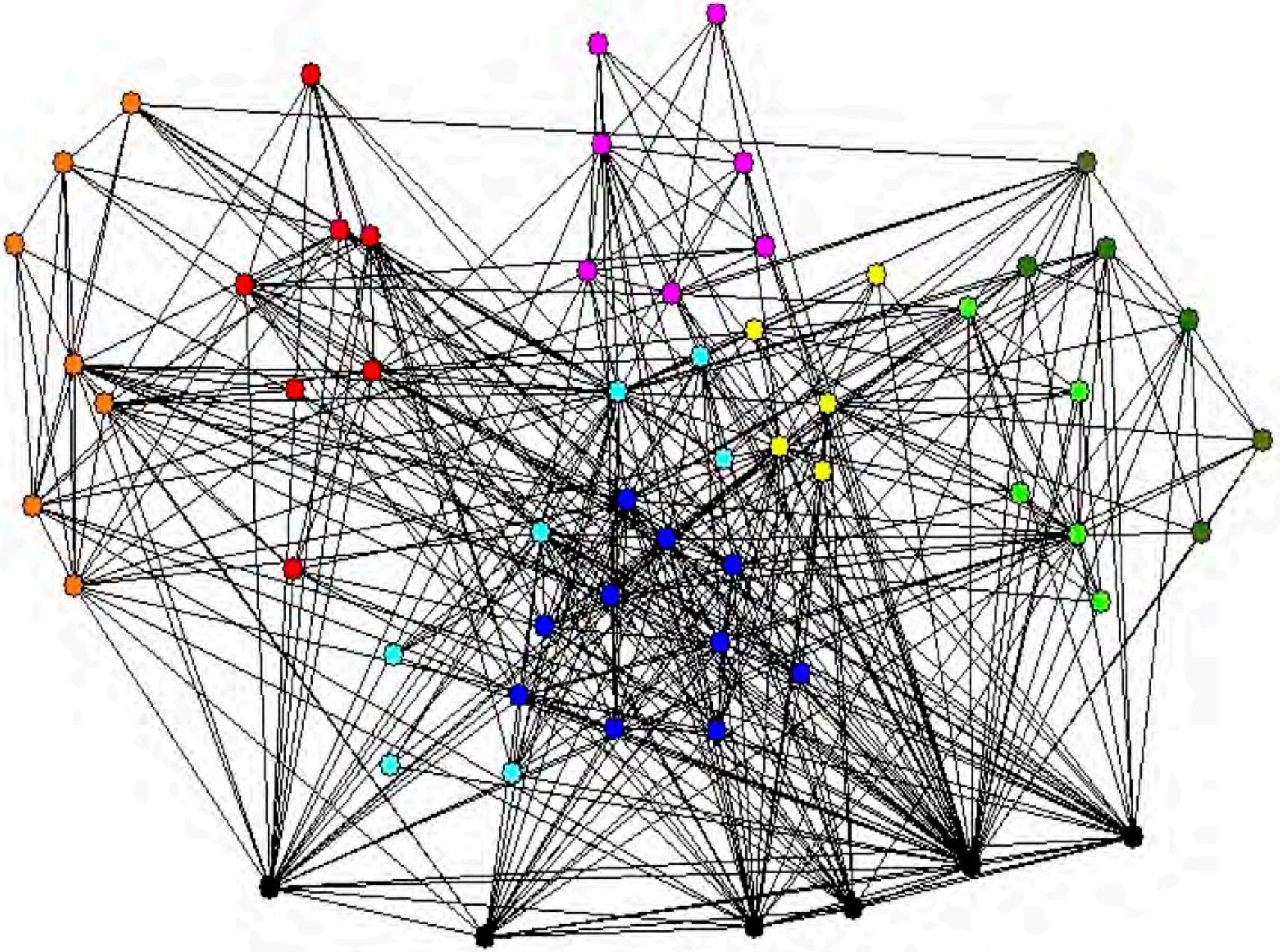
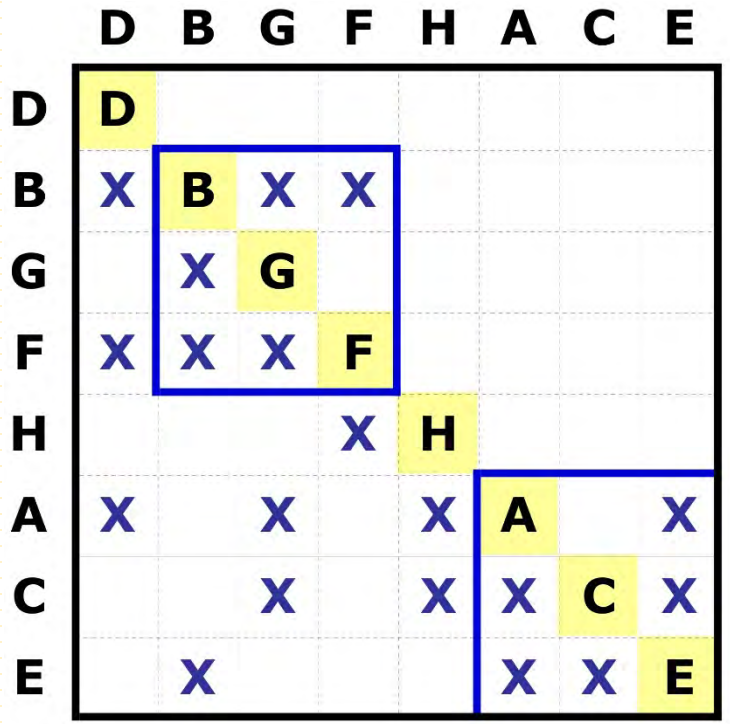


Figure courtesy of M. Sosa

Why DSM?

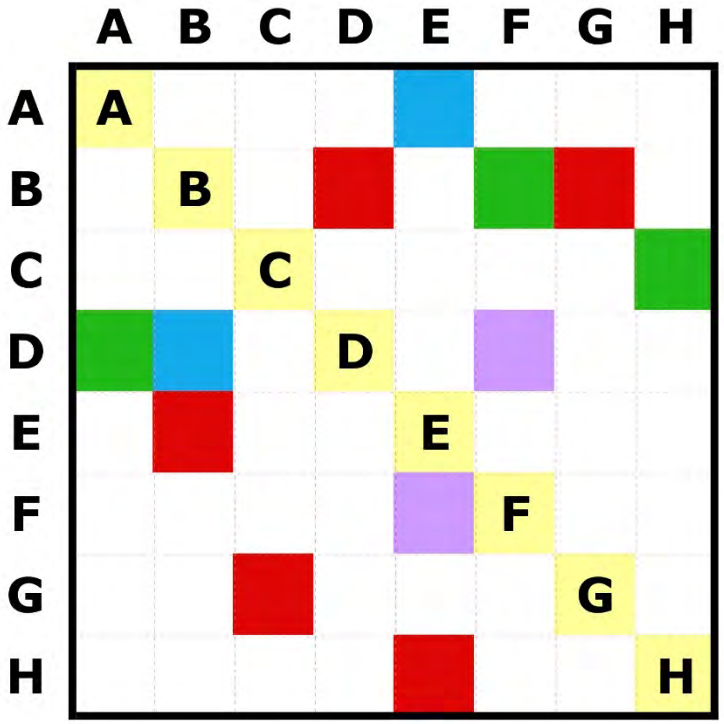
- One of many system modeling tools…
  - …but with advantageous capabilities

- Main advantages:
  - Representation
    - Simple, concise
    - Highlights key architectural patterns (modules, cycles)
  - Innovation
    - Facilitates situation visibility/awareness and systems thinking
    - Stimulates analyses of and innovations in system architectures



DSM Initials and Related Tools

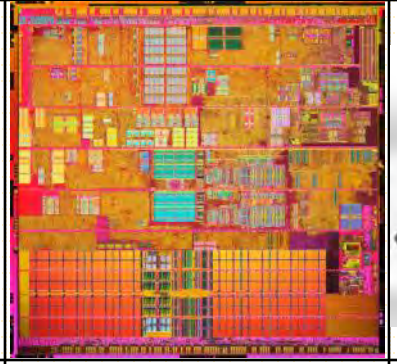
- DSM:
  - Design structure matrix
  - Dependency structure matrix
  - Decision structure matrix
  - Dependency source matrix
  - Dependency structure method
  - Dependency and structure modeling
- Related tools:
  - Dependency map, Precedence matrix
  - Contribution matrix, Reachability matrix, Visibility matrix
  - N^2 chart, DoDAF's SV-3
  - "Attic" of the "House of Quality" (top of QFD matrix)



Where DSMs Have Been Applied

- Automotive (Ford, GM, BMW, Fiat, Saab, Daimler, …)
- Aerospace (Airbus, Boeing, Lockheed Martin, Pratt & Whitney, Rolls Royce, Saab, …)
- Electronics (Hewlett-Packard, Xerox, Intel, Kodak, Nortel, …)
- Building construction
- Military
- Government
- *And many, many others…*
- *Products, processes, and organizations…*
- *All kinds of complex systems…*

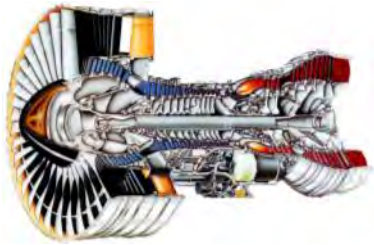
23rd International DSM Conference
October 12-14, 2021 Montreal, QB
dsm-conference.org

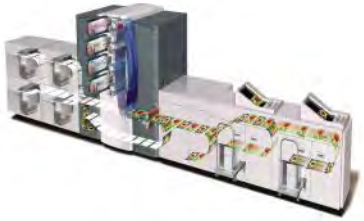













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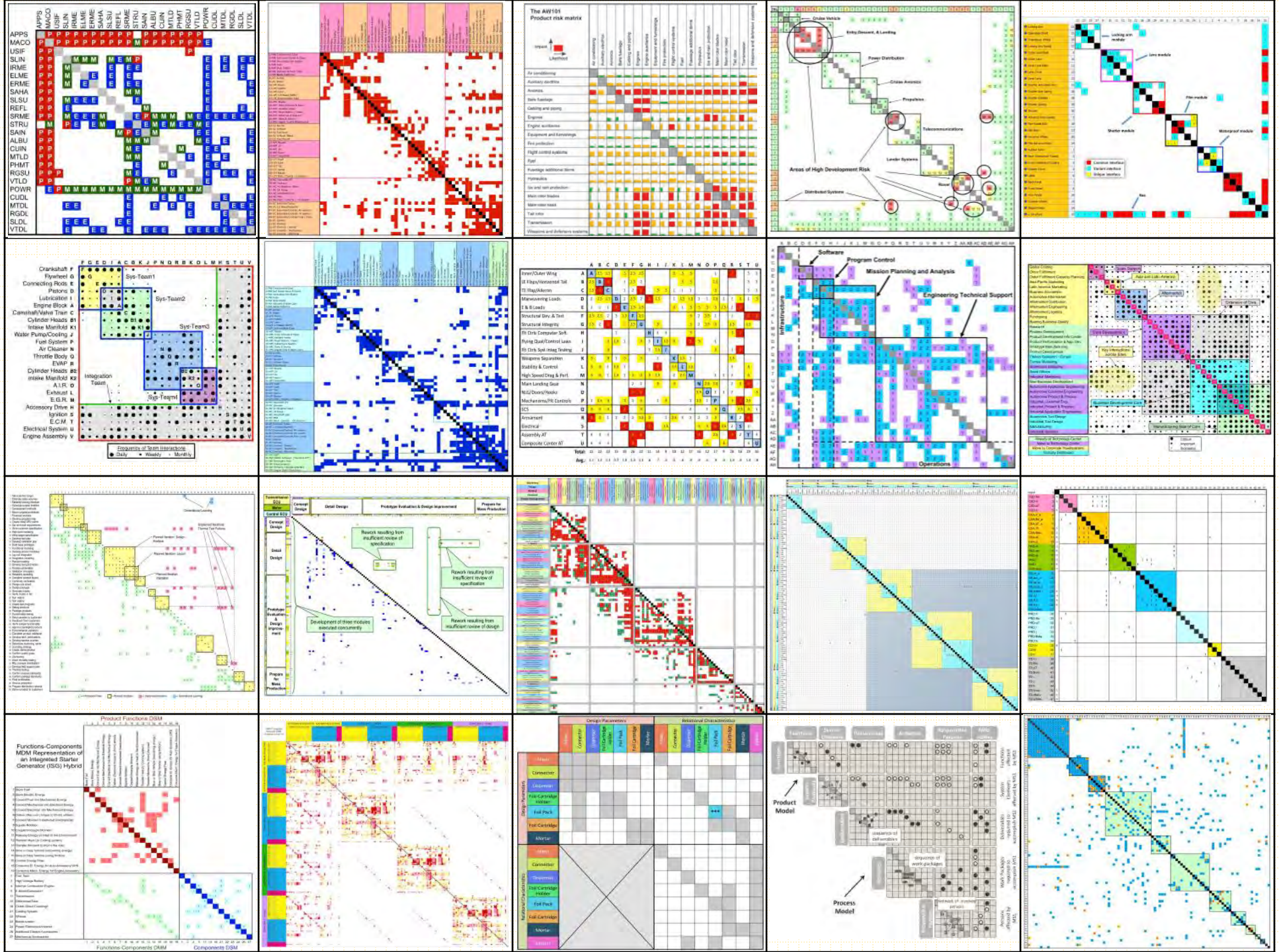
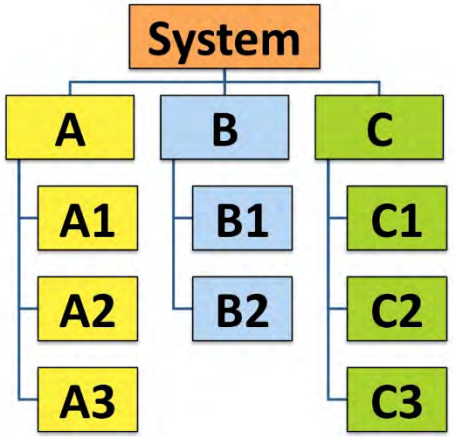


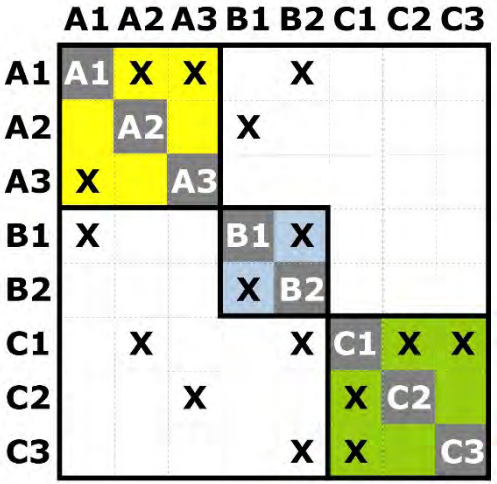
Product Architecture

- Definition: "The arrangement of components interacting to perform specified functions"
- "The architecture of a product is embodied in its components, their relationships to each other and to the product's environment, and the principles guiding its design and evolution"
- "The terms **product architecture** and **system architecture** are used interchangeably in certain contexts"
- Modules implement one or a few functions entirely
- Relationships among modules should be well defined
- Modular architecture has advantages in simplicity and reusability for a product family or platform
    - E.g., Swiss Army knife

Why Does It Matter?

- Product (system) architecting is becoming increasingly visible and important (DoDAF)
- Intelligent product **decomposition is important for understanding** and managing product complexity and evolution
- **Understanding enables innovation**
- Product architecture **innovation can be a source of competitive advantage** (Henderson & Clark 1990)
- Product decomposition requires an understanding of the **elements** and their **relationships** (interfaces)
- **Relationships** among elements are what give systems their **added value** (Rechtin 1991)
- The greatest **leverage** in system architecting is at the **interfaces** (Rechtin 1991)
- Product modularity enables product platforms, P^{3}I (pre-planned product improvement), and process and organization design





Modeling Approach

1. Decompose the product into its components

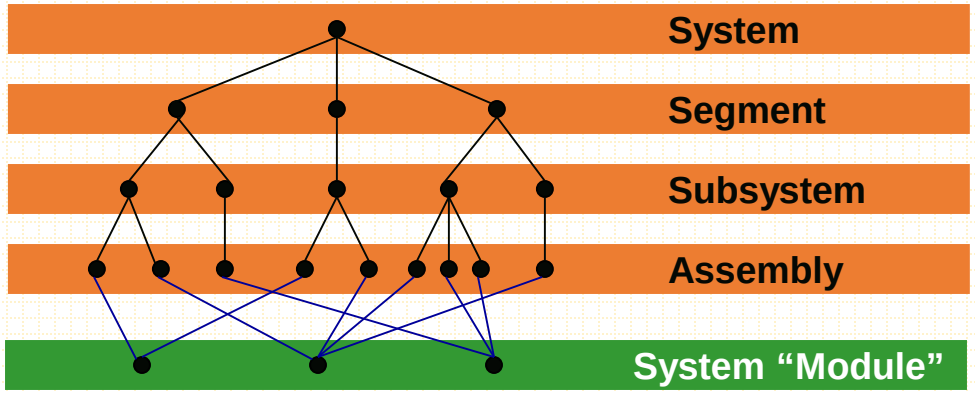
2. Document the relationships among the components using a DSM

3. Cluster (integrate) the components

Product Decomposition and Integration

Step 1:

Step 3:

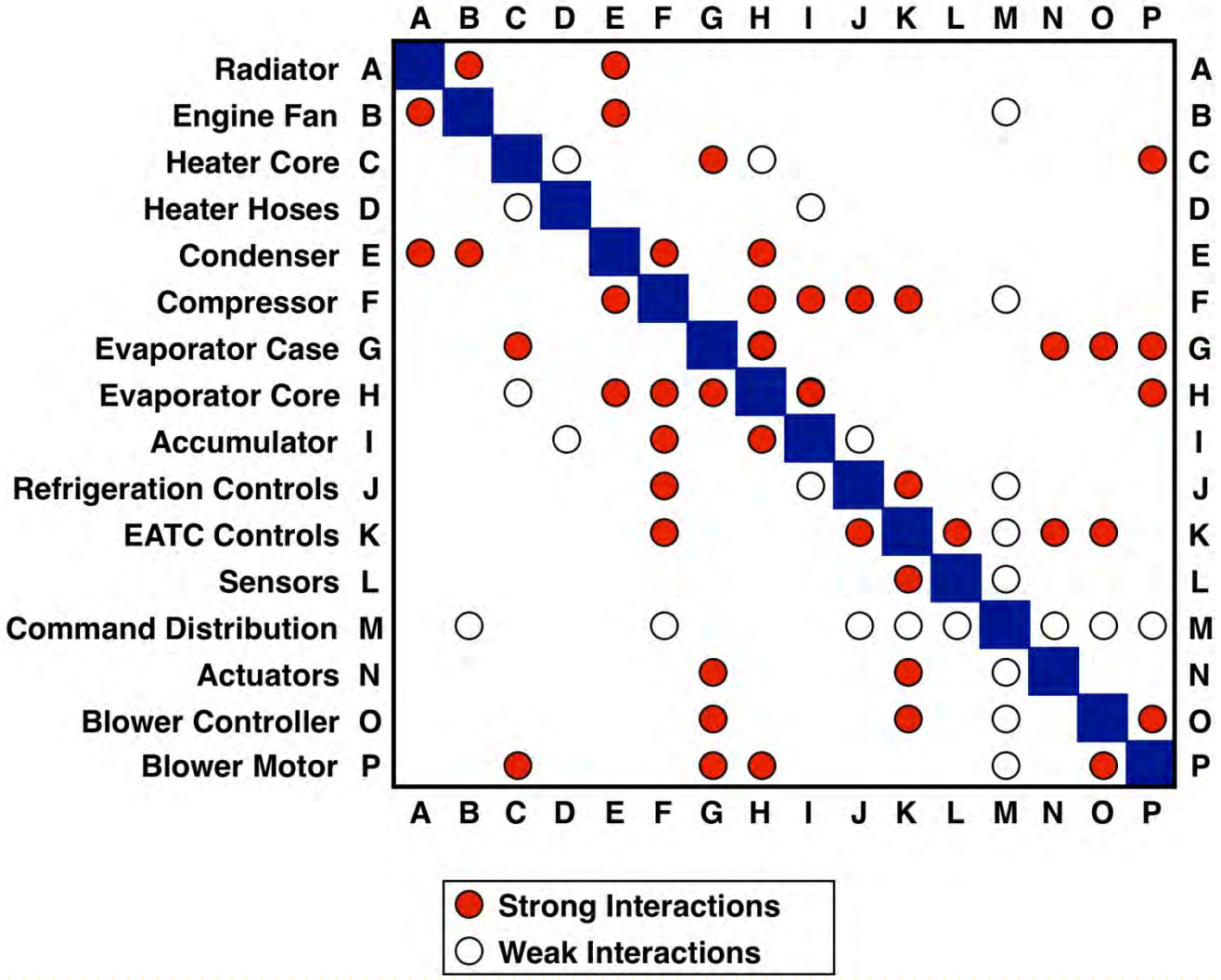


Adapted from (Pimmler & Eppinger 1994)

Step 2: Documenting Relationships

Example: Automobile Climate Control System at Ford

- Begin with a simple DSM (e.g., binary or trinary)
- Document all relationships



Classify and Quantify the Relationships

Types of Relationships (Examples)

Spatial (S)	Needs for adjacency or orientation between two elements
Energy (E)	Needs for energy transfer/exchange between two elements (e.g., power supply)
Information (I)	Needs for data or signal exchange between two elements
Material (M)	Needs for material exchange between two elements

Quantifying Spatial Relationships (Example)

Required	**2**	Physical adjacency is necessary for functionality.
Desired	**1**	Physical adjacency is beneficial, but not necessary for functionality.
Indifferent	**0**	Physical adjacency does not affect functionality.
Undesired	**-1**	Physical adjacency causes negative effects but does not prevent functionality.
Detrimental	**-2**	Physical adjacency must be prevented to achieve functionality.

Adapted from (Pimmler & Eppinger 1994)

Material Flow Relationships Only

Example: Automobile Climate Control System at Ford

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Radiator	A	A	2														
Engine Fan	B	2	B			2											
Heater Core	C			C													2
Heater Hoses	D				D												
Condenser	E		2			E	2		2								
Compressor	F					2	F		2	2							
Evaporator Case	G							G									2
Evaporator Core	H					2	2		H	2							2
Accumulator	I						2		2	I							
Refrigeration Controls	J										J						
Air Controls	K											K					
Sensors	L												L				
Command Distribution	M													M			
Actuators	N														N		
Blower Controller	O															O	2
Blower Motor	P			2				2	2							2	P

Figure ©2001 IEEE from (Browning 2001); adapted from (Pimmler & Eppinger 1994)

Clustering Based on Material Flow Relationships

Example: Automobile Climate Control System at Ford

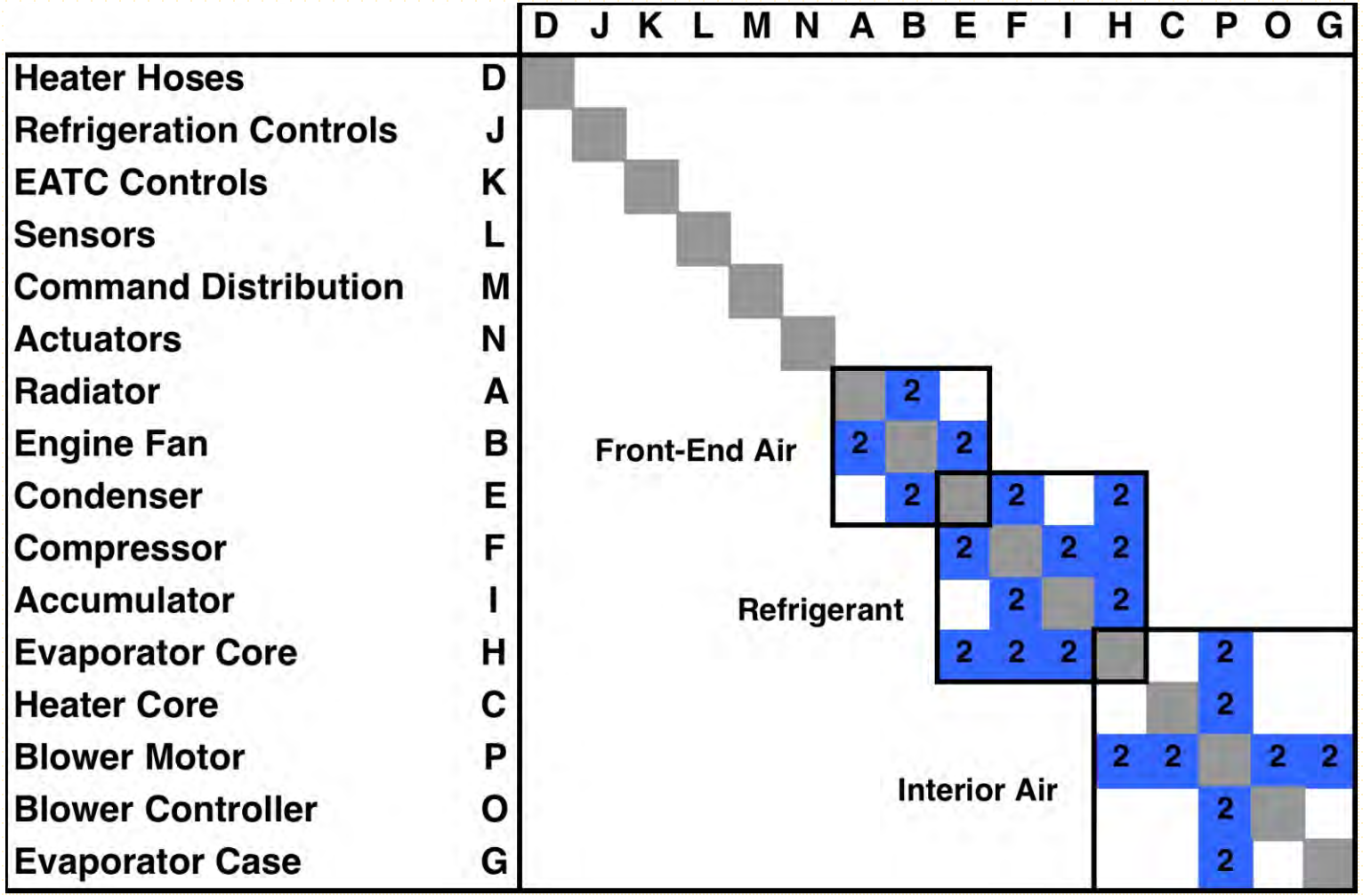
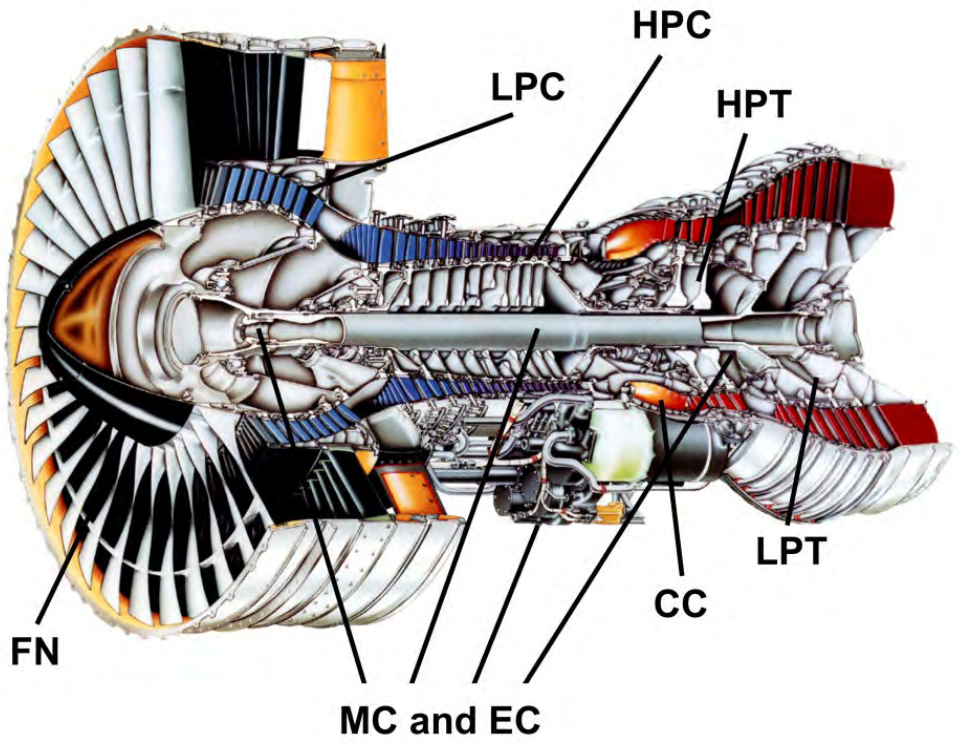
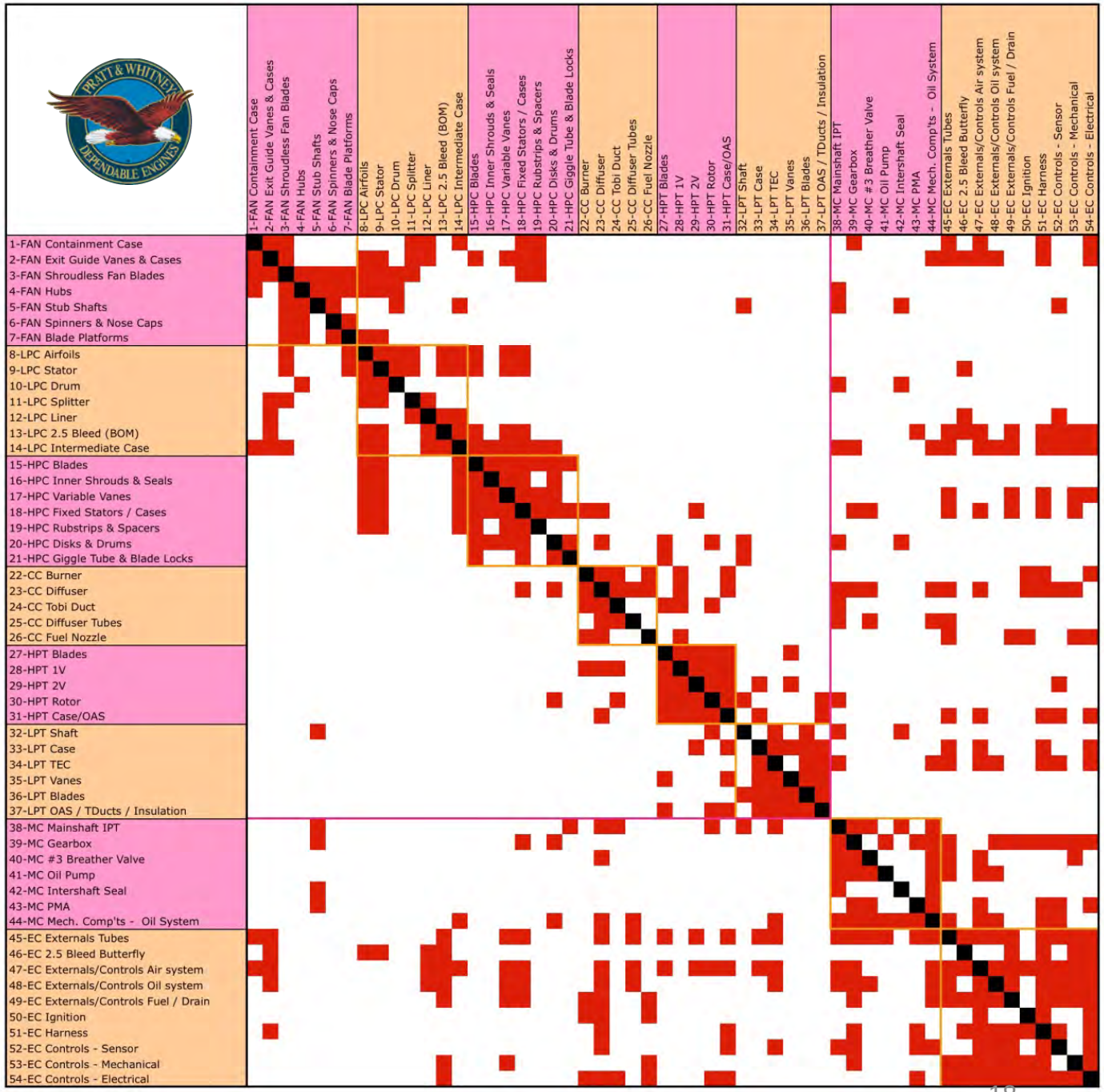


Figure ©2012 MIT Press (Eppinger & Browning 2012)

Bigger Example: P&W4098 Jet Engine

- **8 Subsystems**
- **54 Components**
- **569 Relationships: Spatial, Structural, Energy, Materials, Data, Controls**

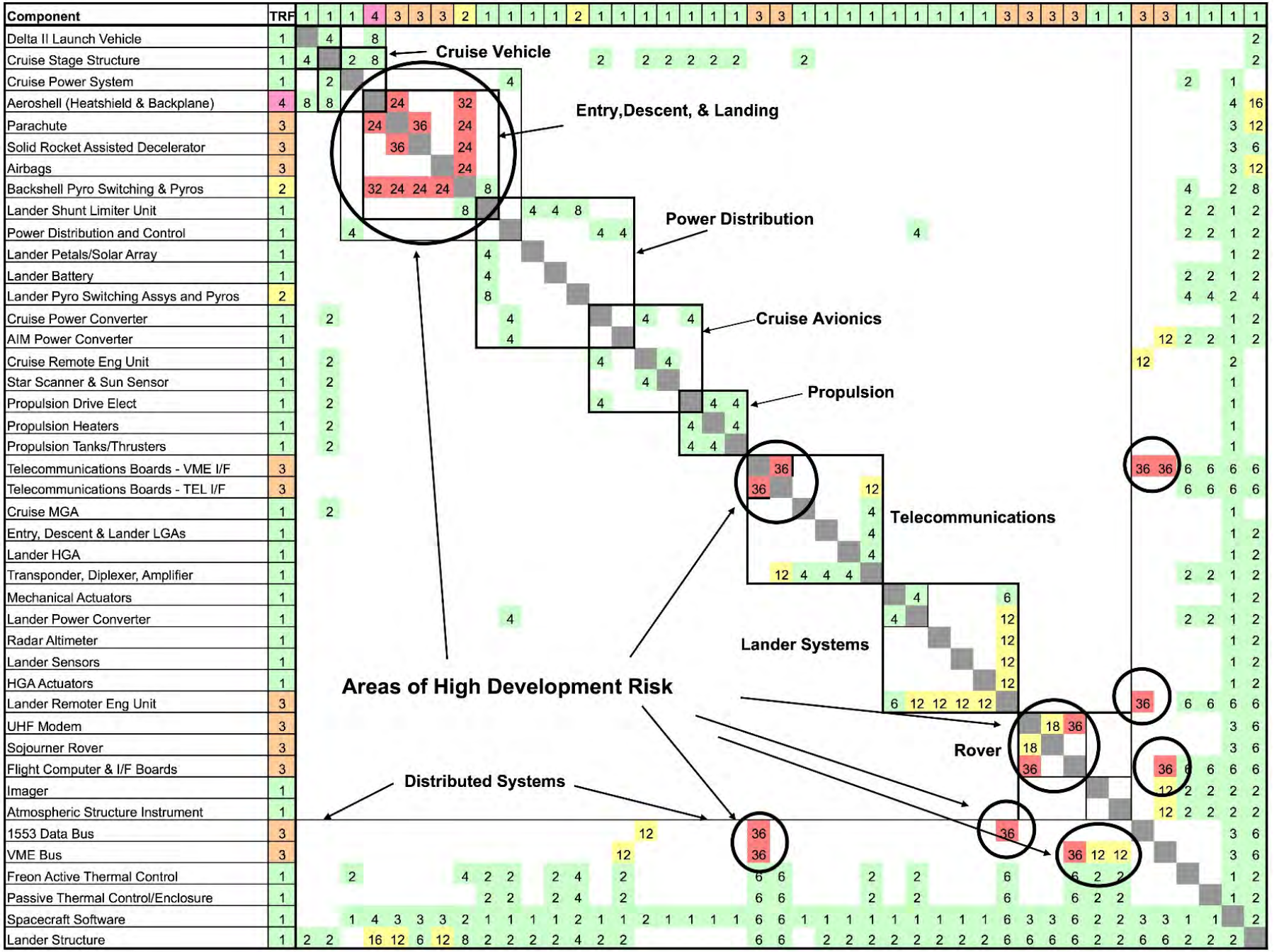




Technology Risk DSM for Mars Pathfinder

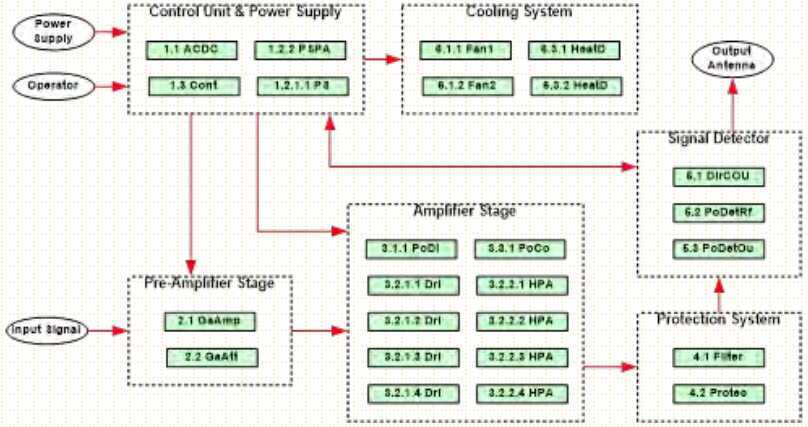
- Components: technology risk factor (1-5)
- Relationships: physical, energy, and/or information (0-2 ea.; 0-6 total)
- Off-diagonal cells: product of both components and their relationships (0-150)

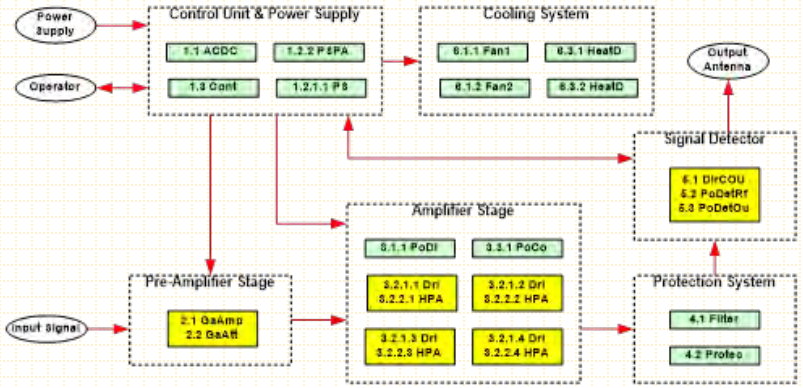
Mars Pathfinder Technology Risk

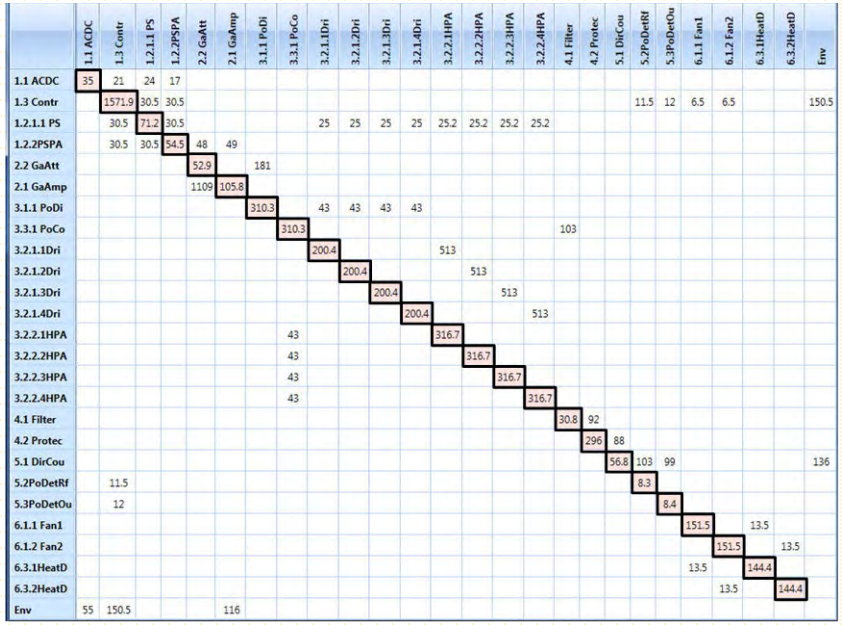


Design for Adaptability, SSPA at TTI, Spain

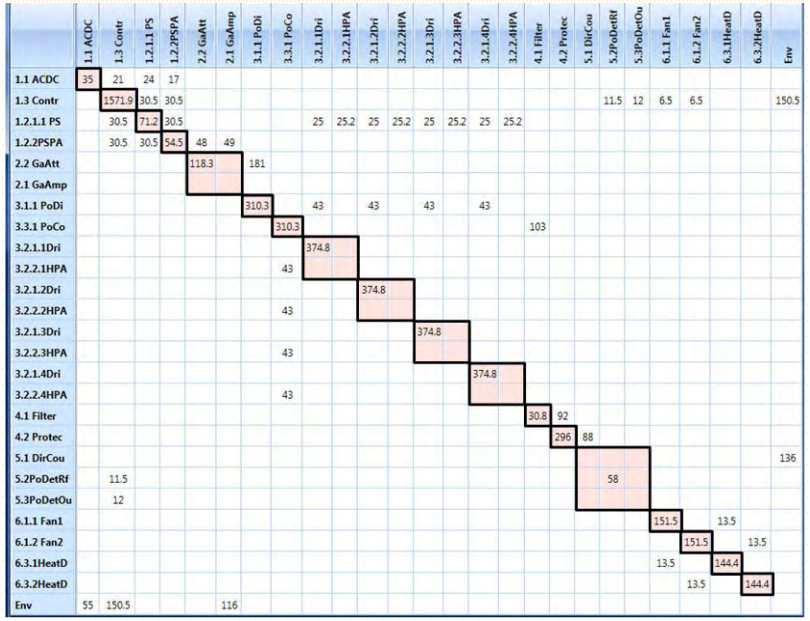
- Component option values
- Interface costs
- Captured in DSM
- AAV objective function and GA used to optimize modularity







(a) After splitting, AAV = 137.3



(b) Optimized, AAV* = 2,875.3

Figures © Wiley (Engel et al. 2017, *Decision Sciences*)

Insights from Product Architecture DSM

- Provides a useful representation for product (system) components and their relationships
- Can be analyzed via clustering (integration analysis), which:
  - Remains somewhat of an art, although several objectives can be identified
  - Can generate and represent alternative perspectives on system architecture
  - Can help improve architectural understanding
  - Facilitates architectural innovation
- Other applications: portfolio segmentation, knowledge capture, interface management, analysis of outsourcing, etc.

For More Information

- Eppinger, S.D. and T.R. Browning (2012) *Design Structure Matrix Methods and Applications*, Cambridge, MA: MIT Press.

- Browning, T.R. (2001) "Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions," *IEEE Transactions on Engineering Management*, 48(3): 292-306.

- Browning, T.R. (2016) "Design Structure Matrix Extensions and Innovations: A Survey and New Opportunities," *IEEE Transactions on Engineering Management*, 63(1): 27-52.

- Available via TysonBrowning.com

Some DSM Clustering Tools

- Manual manipulation in a spreadsheet works for small and/or sparse matrices
- A basic algorithm is available as an Excel macro at www.DSMweb.org
- DSMmatrix (www.ProjectDSM.com)
- LOOMEO by Teseon (www.Teseon.com)
- Soley Studio
- Cluto by Karypis Lab (http://glaros.dtc.umn.edu/gkhome/views/cluto)
- UCINet

How People in Science See Each Other