

Programmatic Complexity & Interdependence: Emerging Insights and Predictive Indicators of Development Resource Demand

Authors:

Robert M. Flowe
ODUSD(A&T)/SSE/SI

Maureen Brown
UNC Charlotte

Paul L. Hardin, III
Technomics

To a large extent, the network has become an even more important component of system architectures. Although security concerns remain high, especially within the DoD, there has been a clear trend toward linked systems.

Report of the Defense Science Board Task Force on Defense
Software November, 2000

For Research Purposes Only

The views expressed are those of the author and do not represent
the policies of the Department of Defense or the
Office of the Deputy Under Secretary of Defense (Acquisition and Technology)

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE MAR 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Programmatic Complexity & Interdependence: Emerging Insights and Predictive Indicators of Development Resource Demand			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Office of the Deputy Under Secretary of Defense (Acquisition and Technology), ODUSD(A&T)/SSE/SI, Washington, DC, 20301			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES NPS's 6th Annual Acquisition Research Symposium, Monterey CA, 13-14 May 2009					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 18	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

BACKGROUND AND CHALLENGES

- Background
 - Weapon system investments capture a significant share of defense budgets
 - Strong emphasis on Jointness generated by Capstone Concept for Joint Operations (2009)
 - Joint requirements conveyed to systems acquisition process via Joint Capabilities Integration and Development System (JCIDS)
- Challenges
 - To what extent has the focus on joint solutions impacted the acquisition process?
 - What can be done to address the increasingly complex joint capabilities requirements?

Implications of JCIDS Joint Capabilities Focus in Systems Acquisition

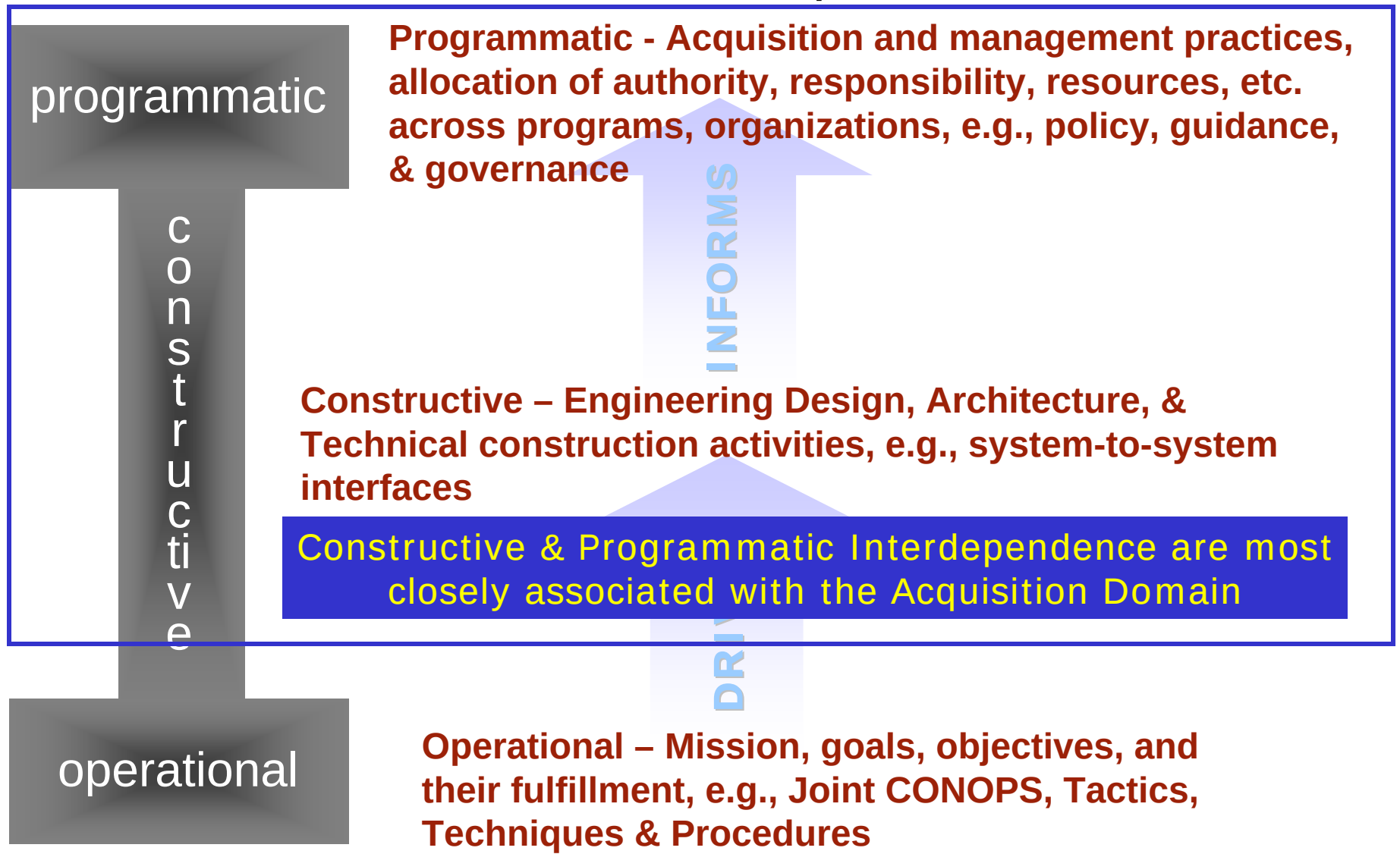
- Emphasis on developing capabilities to support Joint Operations
 - Focus on benefits of multiple systems working together in a 'systems of systems' (SoS) or 'net-centric' context
 - Existing (legacy) and new systems are required to work together towards the capability objective
- In most cases, DoD acquires individual systems
 - Systems, programs defined to fulfill specific requirements, usually in functional, service-specific terms
 - Capability-oriented needs (e.g., net-centric, SoS) may put added demands on systems beyond specified requirements
 - This places additional risks, costs & constraints on program execution
 - Programs impacted by external issues (interdependencies)
 - Difficult to capture in baseline estimates
 - Manifested as cost growth, schedule delay & performance shortfall

Acquiring Defense Capabilities: Nonlinear Scale Effects and Interdependence

- Conventional measures of size no longer predict effort & cost at the extremes
 - Nonlinearity in scaling effects break conventional cost models
 - Fail to account for increased integration & coordination costs
- Extra-programmatic factors confound traditional methods
 - Unpredictable, chaotic nature of program interactions reduce management control
 - Adverse incentives regarding external factors impede proactive planning
- Not just a Joint Program or SoS Problem
 - Any program can be affected
 - Evidence of Interdependence among programs
 - Explicit (as in SoS) or implicit
 - Can take many forms

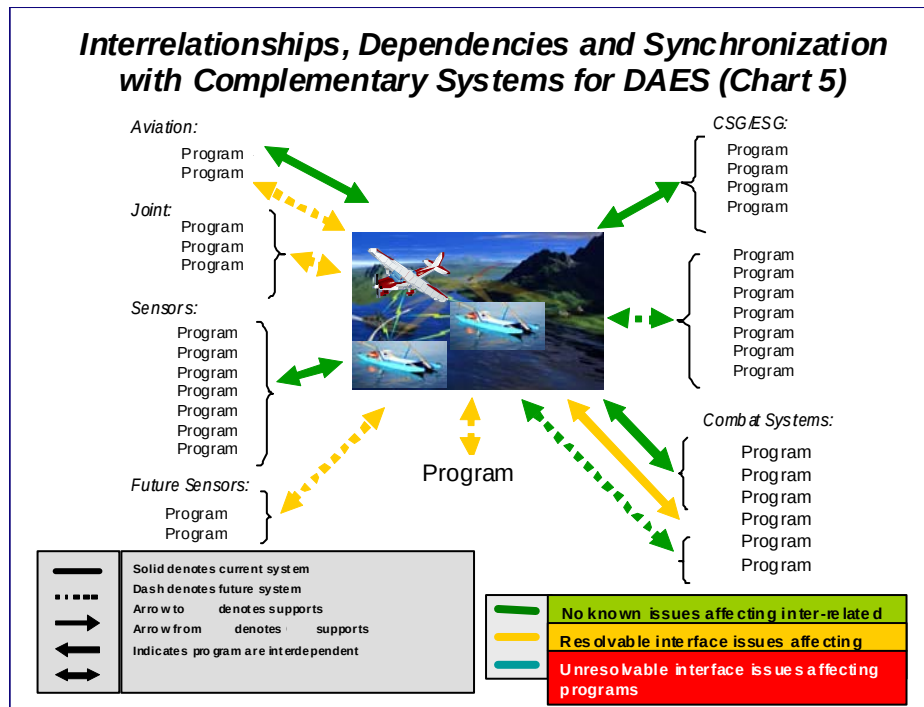
Examining interdependence as a distinct feature may provide useful insight into program behaviors

Unpacking Interdependence: Three Dimensions of Interdependence



Current Treatment of Interdependence

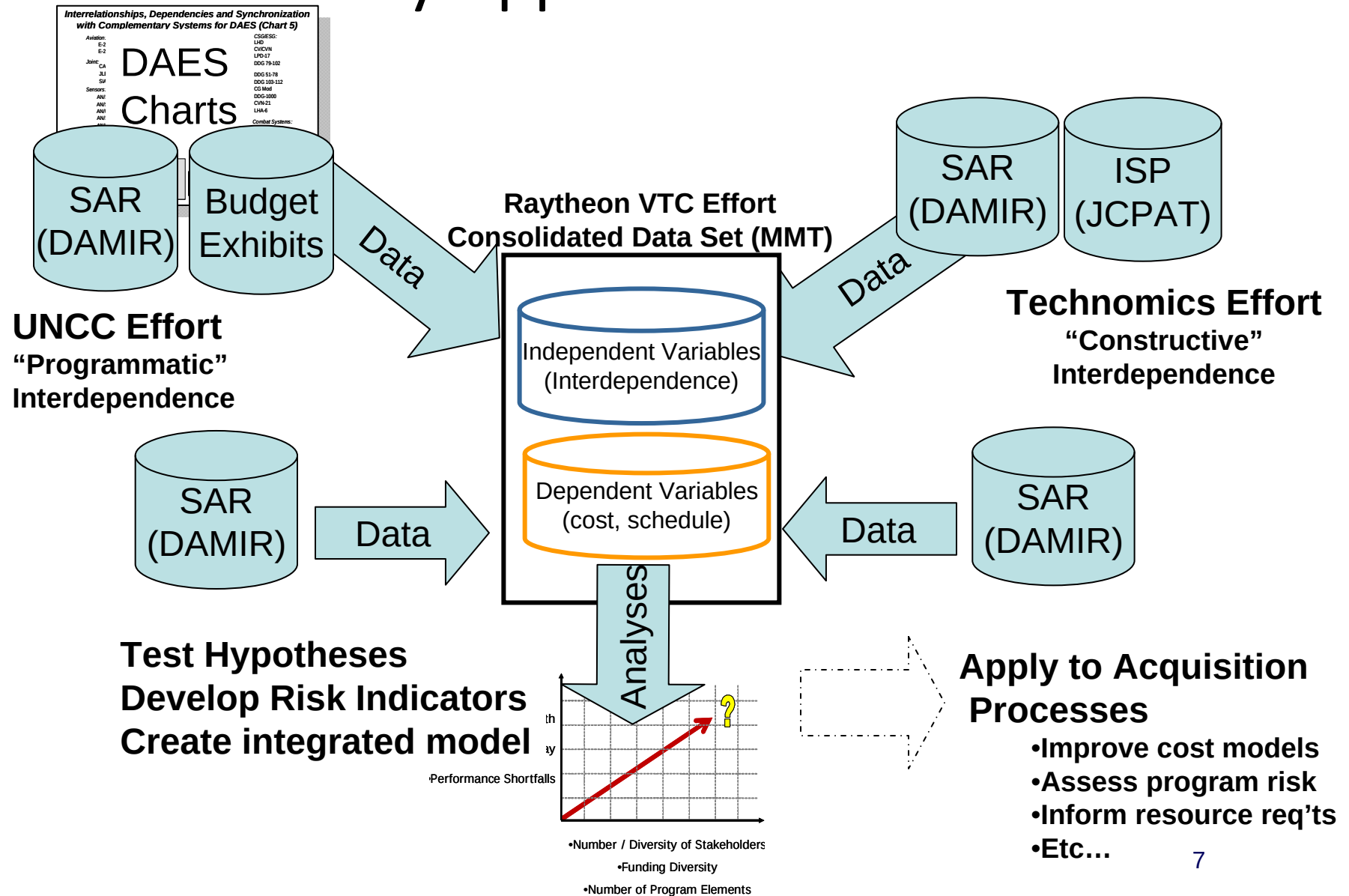
DAES Depiction of Interdependence (representative)



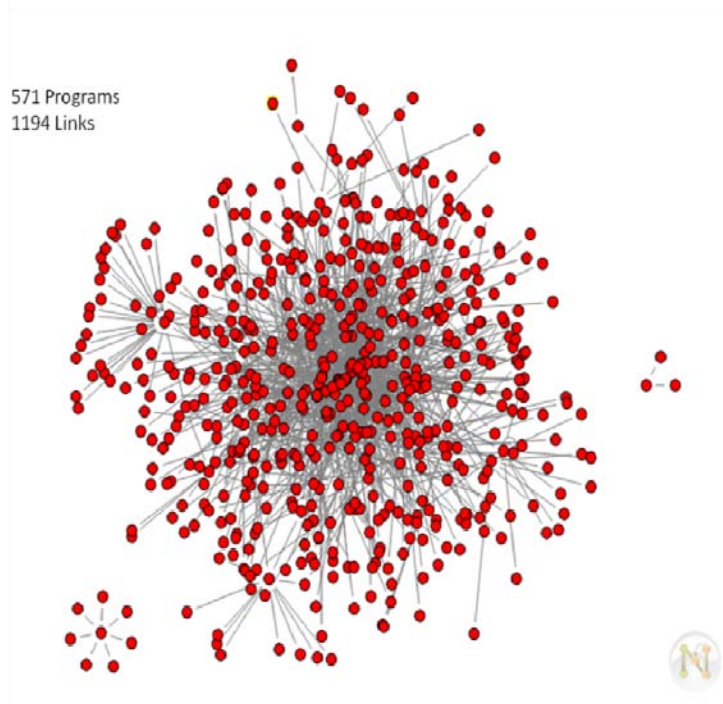
- Current DAES View provides some insight regarding interdependence
- Concern about consistency & objectivity of format
- Most relationships with non-reporting programs
- Hard to assess program risk from this representation

**Subjective Insights are Interesting,
Objective Measures would be Useful**

Study Approach Overview



Views of Programmatic Interdependence



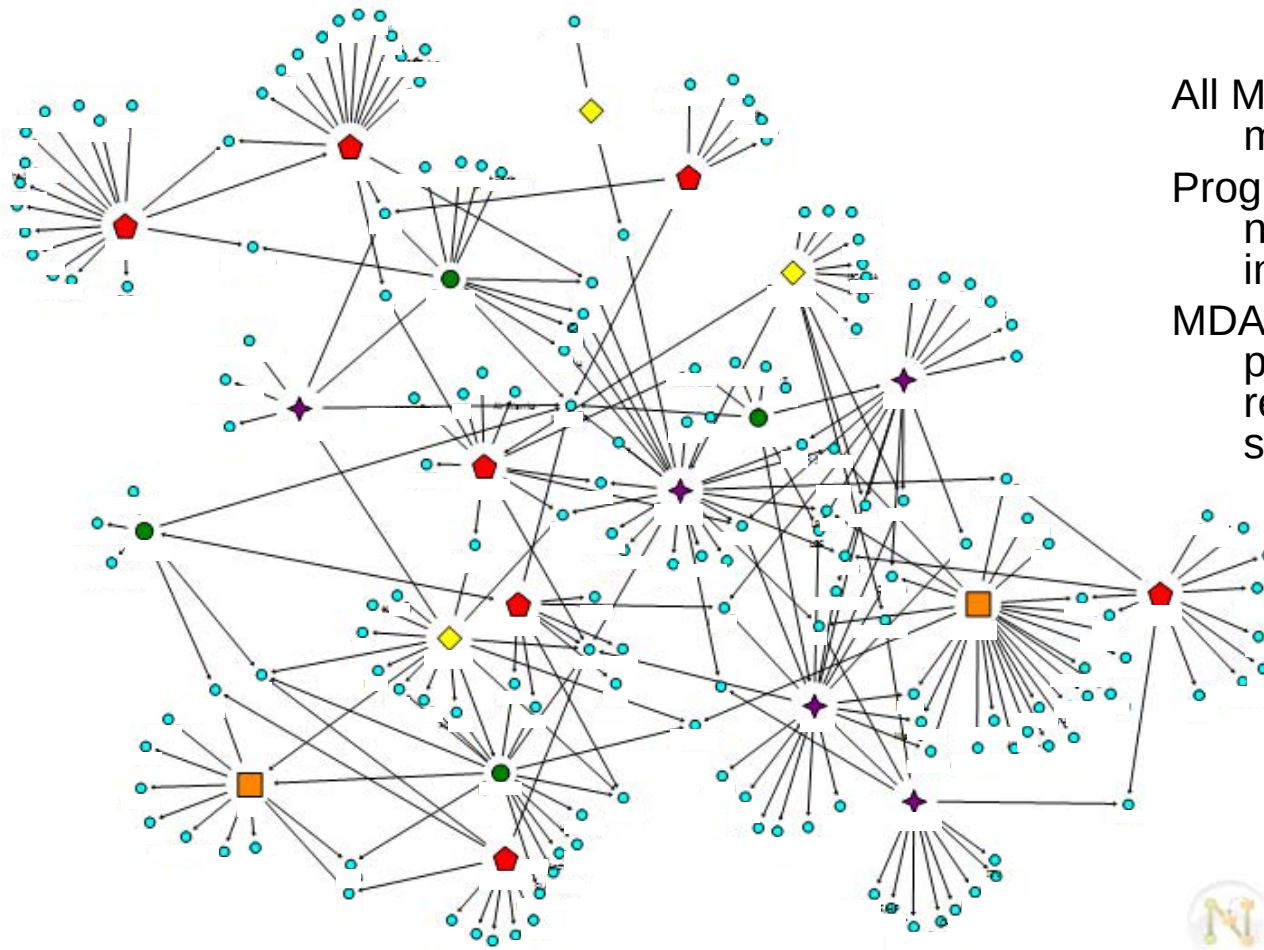
All Programs



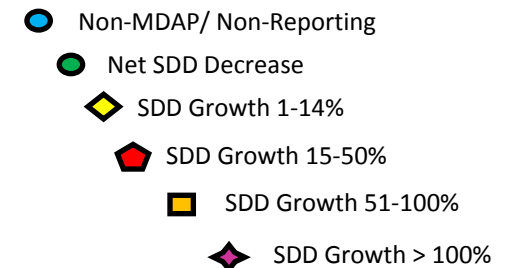
MDAPs Only

Compilation of program dependencies as depicted in 2007 DAES charts

Programmatic Interdependence: Network View



All MDAPs are interdependent in multiple ways
Programs defined as “Joint” are not obviously more interdependent than non-joint.
MDAPs are linked mainly to programs that are not required to report on program status.



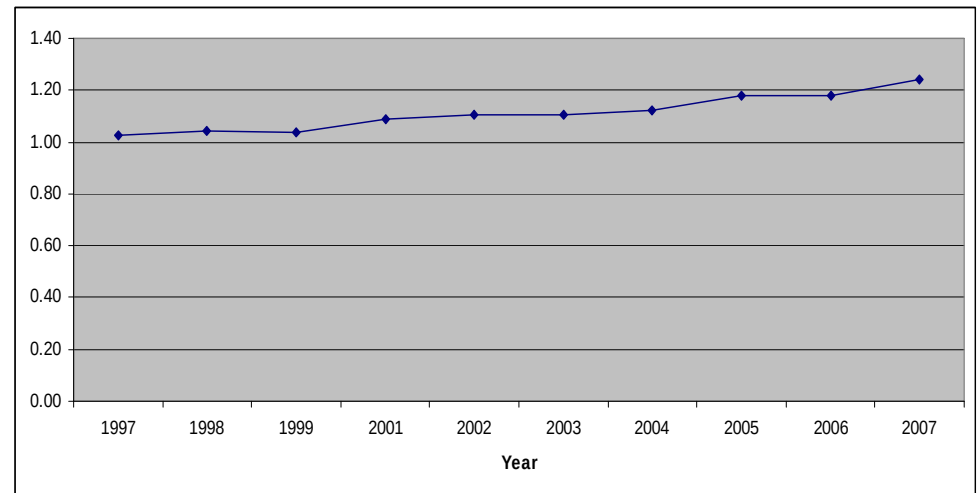
Interdependencies from DAES charts for programs post M/S-C;
Cost growth data from SAR

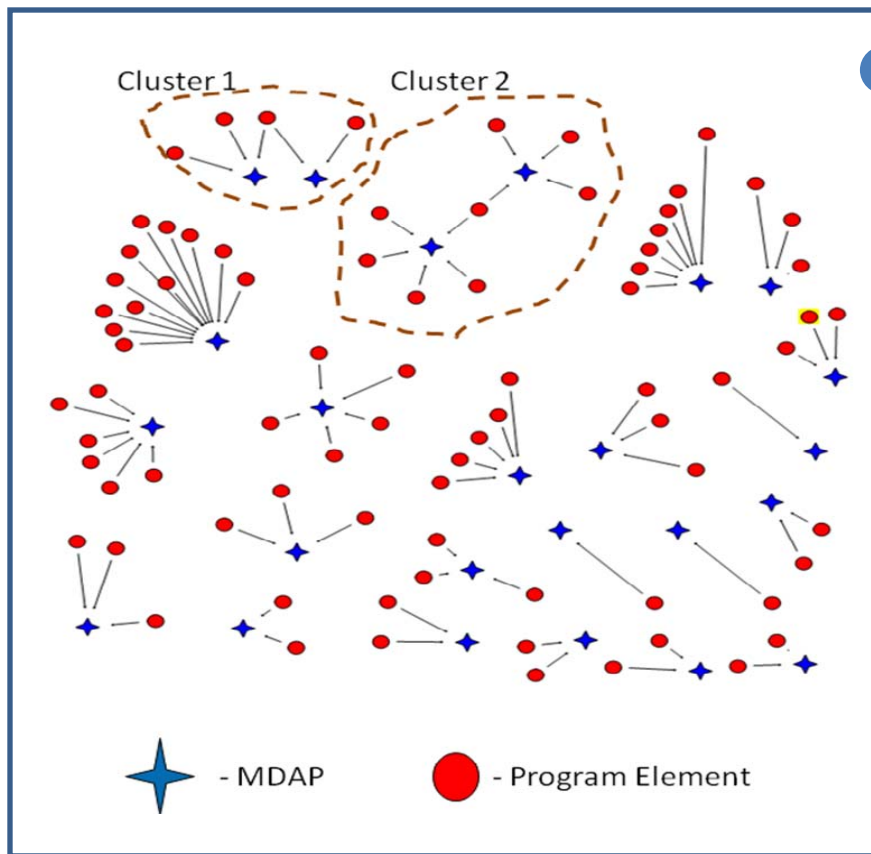
Programmatic Interdependence Evolving Over Time

Year	Number of Linkages	Number of MDAPs	Number of Program Elements	Ratio of PE's per MDAP	Number of Links per MDAP	Number of Links per PE
1997	82	24	80	3.3	3.4	1.03
1998	96	26	92	3.5	3.7	1.04
1999	87	26	84	3.2	3.3	1.04
2001	113	31	104	3.4	3.6	1.09
2002	116	35	105	3.0	3.3	1.10
2003	117	37	106	2.9	3.2	1.10
2004	135	44	120	2.7	3.1	1.13
2005	159	50	135	2.7	3.2	1.18
2006	257	92	218	2.4	2.8	1.18
2007	319	95	257	2.7	3.4	1.24

Data from SAR

Number of Links
from MDAPs to Program
Elements increases over
sample period (1997-2007)





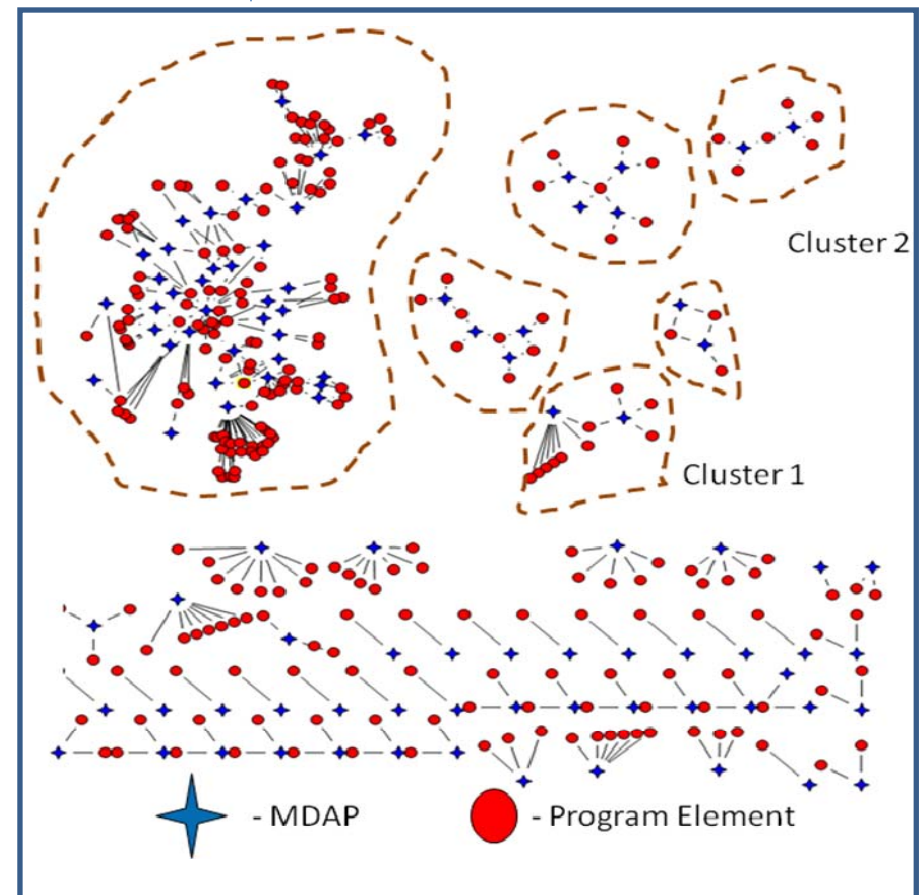
2004

Suggests program
interdependence emerges as
clusters of collaborating programs

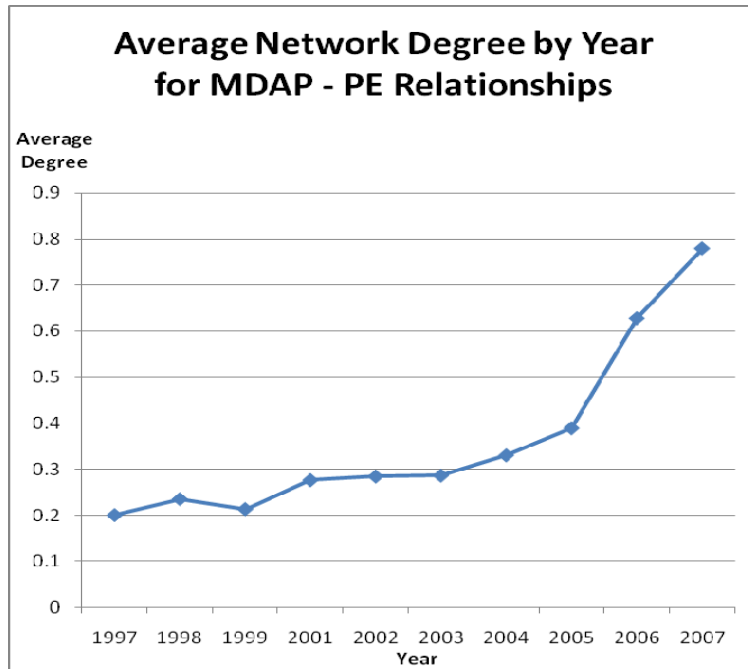
Data from SAR

Program Funding
Relationships :
Multi-Program Clusters
have proliferated and
expanded

2007



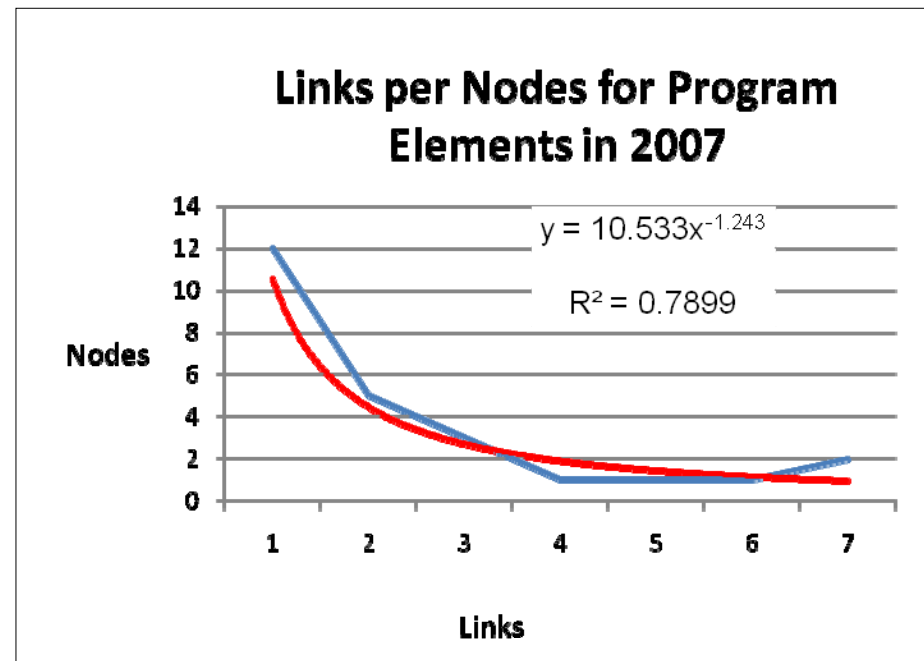
Resource Sharing Among Programs



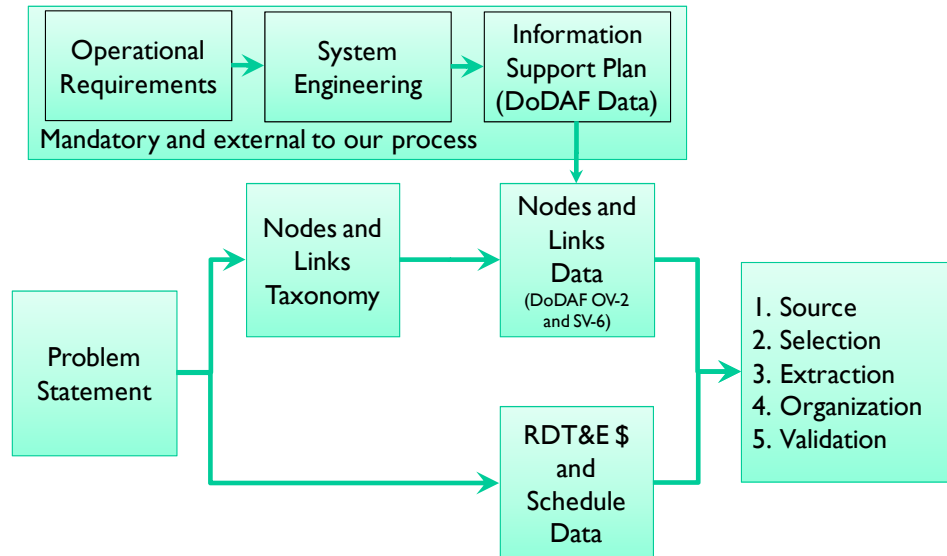
Increasing “connectivity” among programs via their funding program elements...

...suggests programs are becoming more interdependent through shared resources

Data from SAR

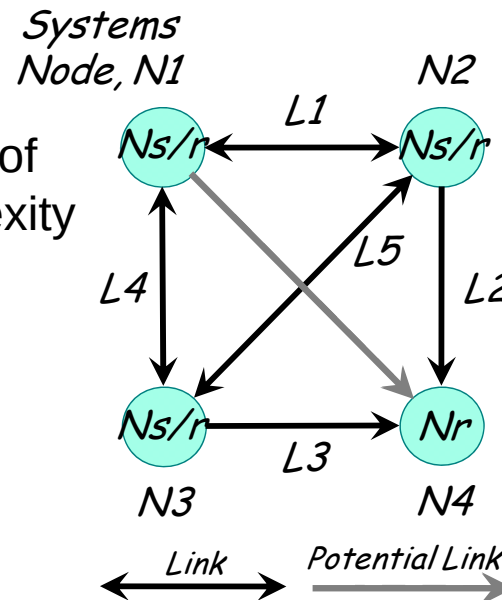


Constructive Interdependence: Methodology



Information Support Plans and DoDAF Artifacts provide insight into the “constructive” dimension of interdependence

Simple counting rules
create objective measures of
interdependence and complexity



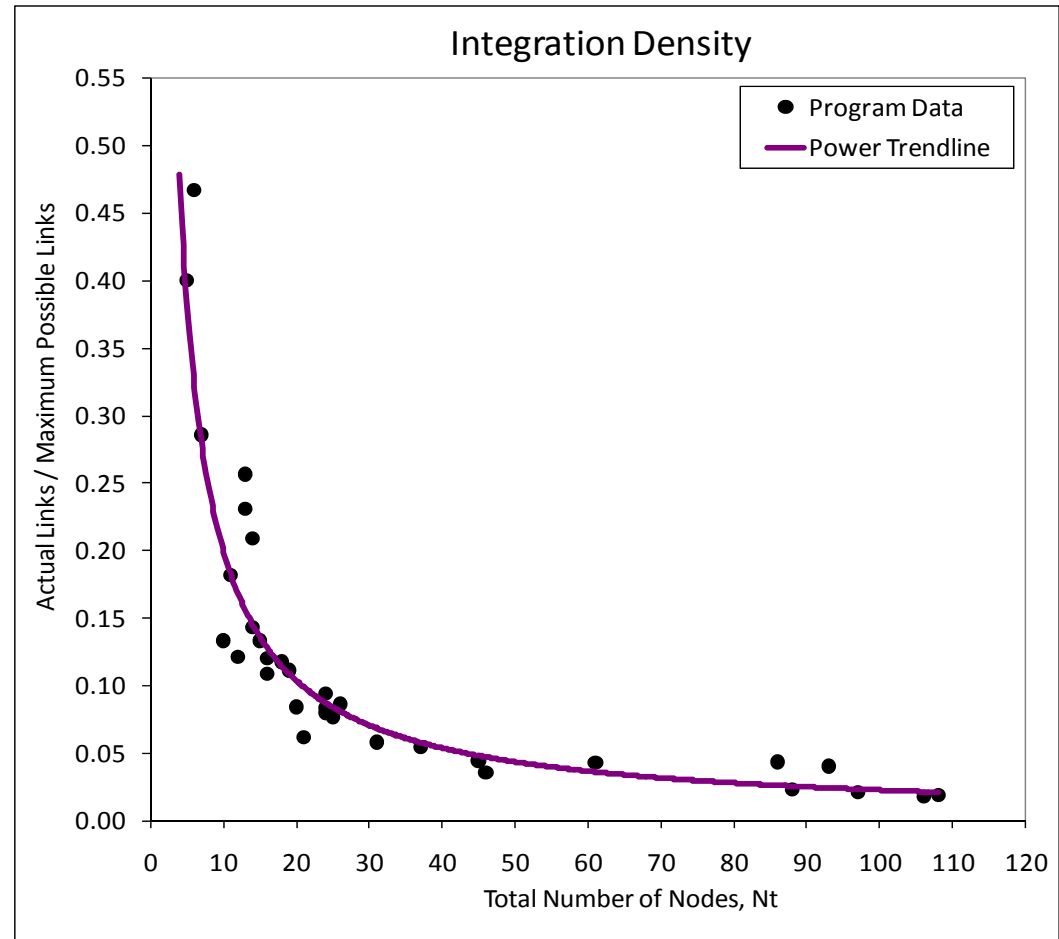
<u>Item</u>	<u>Value</u>
Systems Nodes, N	
Send/Receive, Ns/r	3
Send, Ns	0
Receive, Nr	1
Total, Nt	4
Links, L	
Uni- directional, Lud	2
Bi- directional, Lbd	3
Total, Lt	5
Metcalf Number, $LtMax$	6
Integration Density, $Lt/LtMax$	5/6
Links per Node, Lt/Nt	5/4

Constructive Interdependence: Emerging Patterns

Integration density within MDAPs shows remarkable consistency over a wide range of programs

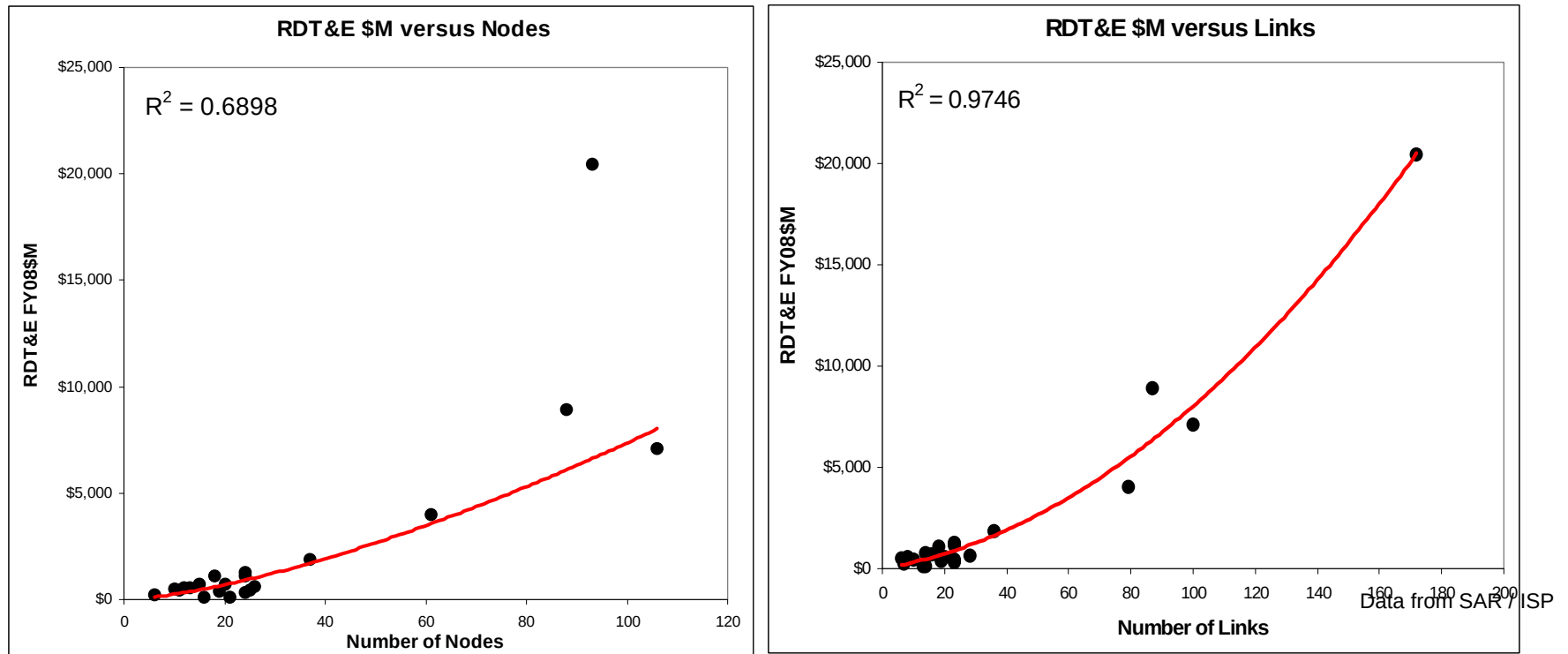
Suggests some underlying principle guides the evolution of complex systems

Relationship has practical utility for inferring development effort with respect to scale



Data from SAR / ISP

Correlation with Resource Demand



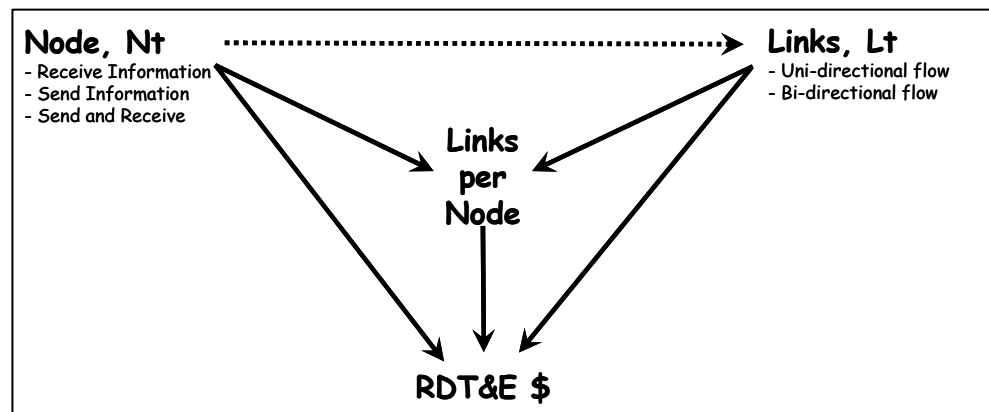
Data suggest a nonlinear relationship between measures of interdependence & complexity and development resource demand (measured in RDTE \$)

Stronger correlation between Links consistent with the notion of interdependence being a key driver

Formulating a Model

Simple relationship between numbers of nodes and links does not account for the following effects:

- Send / Receive nodes are more complex than Send-only or Receive-Only;
- Send-only nodes are more complex than Receive-Only
- Nodes that have more links are more complex than nodes with fewer links.



$$N_e = (dN_{s/r} + gN_s + hN_r) \left(\frac{L_t / N_t}{\text{avg} \left(\frac{L_t}{N_t} \right)} \right)^c$$

“Effective Nodes”
formulation to account for
relative node complexity...

$$RDT \& E\$ = aN_e^b$$

...“plugs in” to a simple nonlinear
relationship for RDTE\$ in terms of
“Effective Nodes”

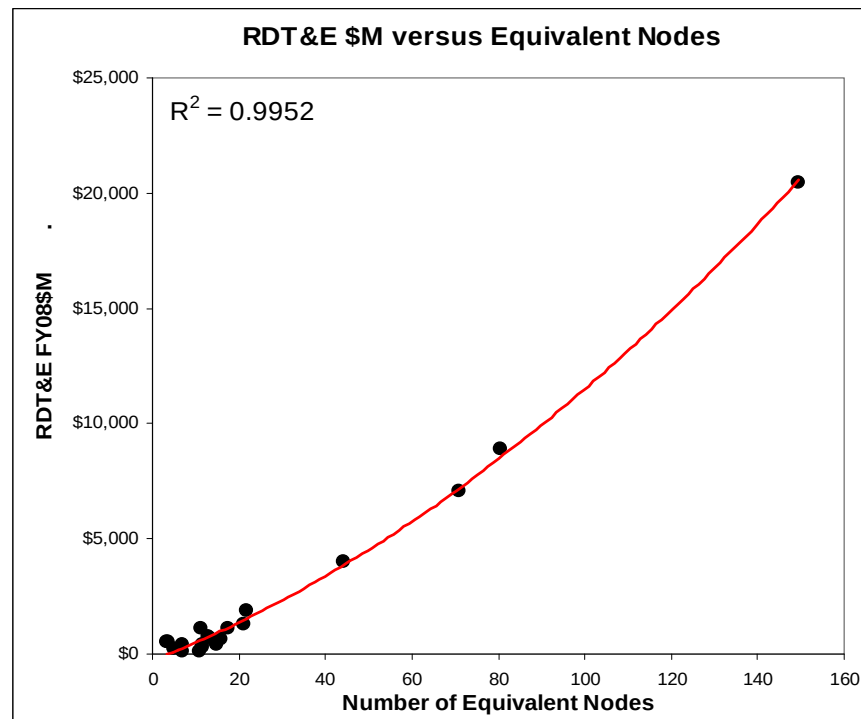
Refining the Model

$$N_e = (N_{s/r} + 0.5N_s + 0.29N_r) \left(\frac{L_t / N_t}{1.02} \right)^{1.22}$$

Model parameters resolved through optimization against MDAP data set

$$RDT\&E\text{ FY08}\$M = 20.7 N_e^{1.38}$$

Significant correlation over large range of MDAP size / complexity



Model provides method to translate measures of interdependence derived from authoritative data into estimates of development resource demand

This correlation may be of significant utility for assessing program development needs or risk

Data from SAR / ISP

Findings/Implications

- 1) Interdependence is pervasive among systems. Limiting consideration of interdependence to programs designated as joint or part of SoS is insufficient.
- 2) Interdependence among programs is increasing, possibly spontaneously to address increasing demands for joint capabilities.
- 3) traditional methods of analyzing risk, while important, need to be supplemented with network analysis techniques to reveal the true scope of the effects of interdependencies.
- 4) Existing data resources, even the relatively aggregate SAR data and the often-disparaged DoDAF artifacts, when combined in an analytically rigorous manner over a sufficiently large sample, can provide significant insights into program behaviors.
- 5) Continued exploration into the nature and effects of interdependence is likely to yield further insights and benefits

For the paper and/or data set, please contact
Rob Flowe at (703) 602-0851 x121; robert.flowe@osd.mil