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Quantifying Systemic Risk and Fragility in the U.S. Defense Industrial Base

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Summary

- This research proposes that centrality and community measures provide critical insight into two macro forces threatening a supply chain
  - Connectedness-based rankings quantify systemic risk
  - Community measures quantify fragility
- A supplier can be both systemically risky and fragile
- We argue that systemic risk, fragility, and imbalance directly relates to a supplier's criticality within a supply chain network

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The Network Structure
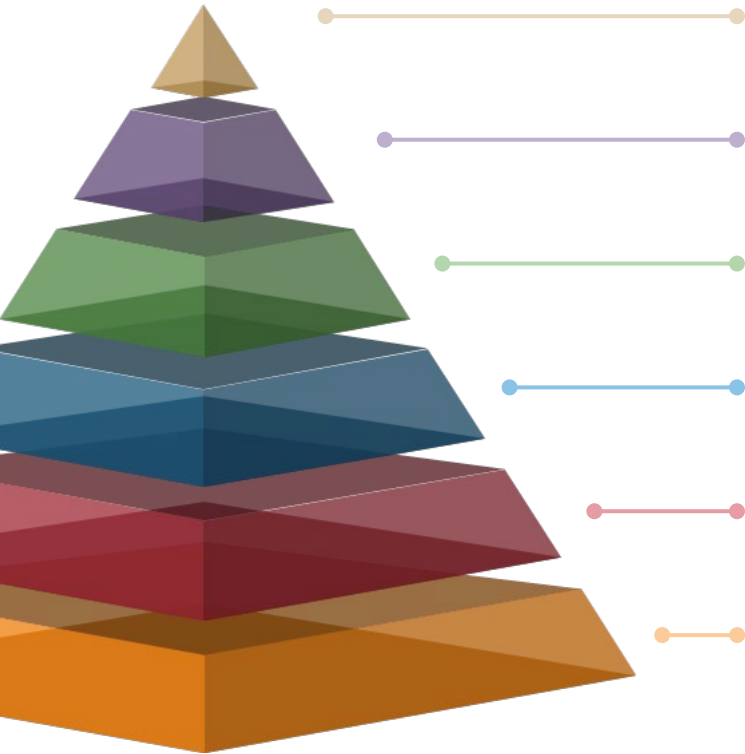
Funding Organization
Example: Department of Defense, Department of Transportation, Department of Energy

Procuring Organization
Example: Department of the Army, Department of the Navy, NASA, DCAA, DCMA

Commodity Code
Example: NAICS or PSC (Aircraft, Missiles, Shipbuilding)

Prime Contractor
Example: Raytheon Technologies, Lockheed Martin, Boeing, MITRE, BAE

Sub-Contractor (Direct Spend)
This is the primary industrial supply base. Examples: TTM, Aerojet, Ducommun, Carleton, Cobham
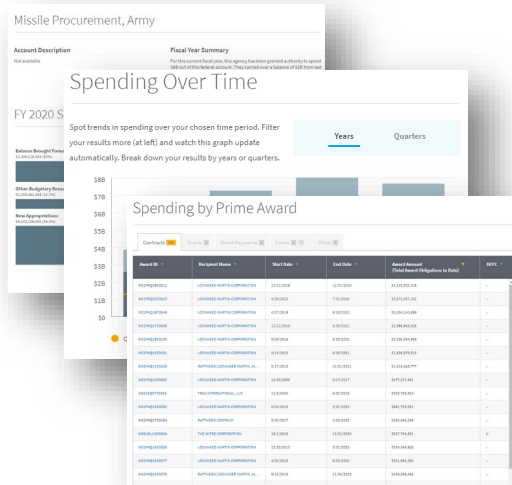
Sub-Contractor Parent
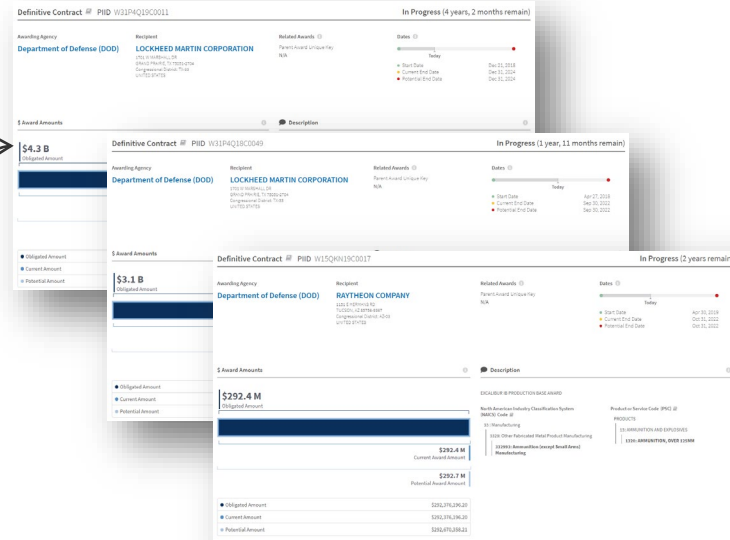Parent or controlling company (if applicable). Example: Berkshire Hathaway, Honeywell

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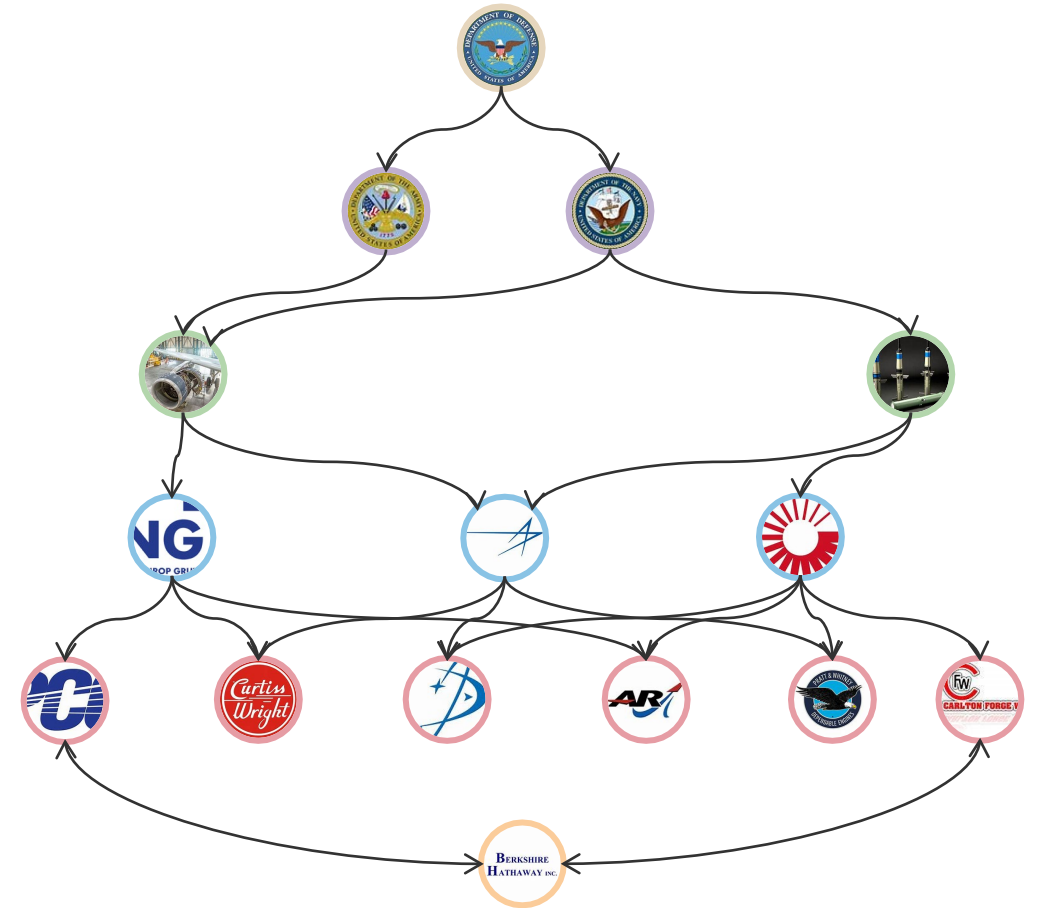
Method
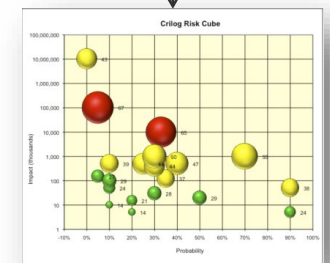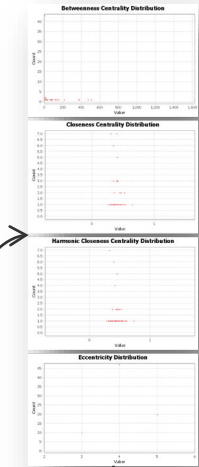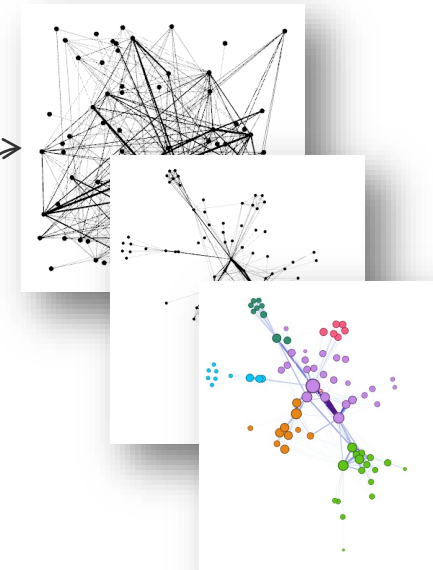
Assess centrality/community

Apply layout algorithm

Identify fiscal year(s) of interest

Pull subcontract award data

Translate into risk/fragility measures

U.S. Department of the Treasury, Bureau of the Fiscal Service. (2021). *USAspending.gov*. Images from https://www.usaspending.gov/

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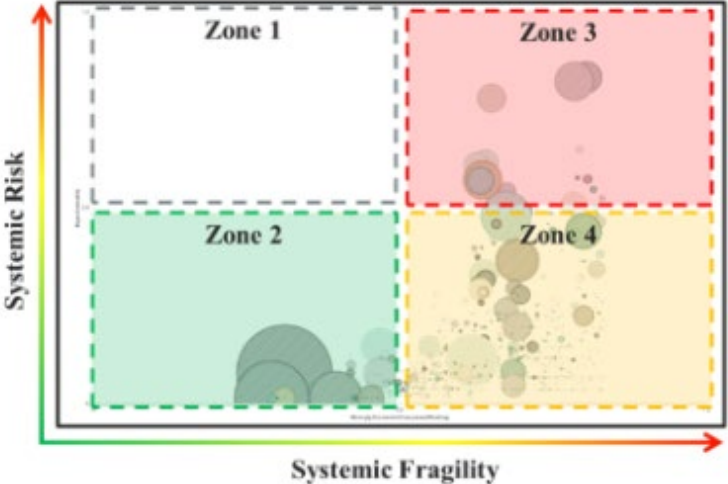WASHINGTON, DC

Measures of Centrality and Community

- Centrality ~ node connectedness

- Community ~ groups of densely connected nodes

- Systemic risk ~ local and network centrality and community

Item	Basis	Measure	DIB Applicability	Source
Degree	Importance score based on the number of links held by each node	Direct connections	In-degree and out-degree measures to better understand the flow of material	(Perera, Bell, & Bliemer, 2018)
Betweenness	The number of times a node lies on the shortest path between other nodes	Network efficiency of flow	High betweenness indicates critical suppliers that are highly active within the network	(Estrada, Higham, & Hatano, 2009)
Closeness	Time required to spread information from a node to the other nodes in the network	Shortest paths between all nodes	Suppliers with high closeness centrality levels support mitigation of the impacts arising from bullwhip effect (Xu, M; Liu, JB; Li, DX; Wang, J;, 2016)	(Buechel & Buskens, 2013)
EigenCentrality	Represents the relative strength or influence over other nodes in the network	Node influence	Quantifying the propagation of failure tied to disruption of a supplier	(Ruhnau, 2000)
PageRank	Reflects influence within the network, but PageRank also considers link direction and weight	Node Influence	The extent of failure propagated through a community of suppliers or across a commodity	(Page, 1998)

| Item	Basis	Measure	DIB Applicability	Source
Network Diameter	Edge count of the shortest path across the network	Complexity	Supports quantification of local community authority, or the lack of authority across a commodity	(Abd-El-Barr, 2009)
Network Density	The level of interconnectivity between nodes	Connectivity	Higher density indicates a more robust supply chain	(Bendle & Patterson, 2008)
Clustering Coefficient	The level of coupling nodes demonstrated	Subsystem or neighborhoods	Assessing program, agency, or prime contractor supply chain dependencies	(Brintrup, et al., 2016)
Modularity	The strength of the allocation of subsystems within a network	Subsystem or neighborhoods	Detecting community structure within a NAICs group	(Fortunato, Barthelemy, & yes, 2007)

Measures of systemic risk and fragility

- Systemic risk ~ increased influence carries a more significant negative impact on the overall network

- Fragility ~ vulnerability or lack of network robustness (Perera, Bell, & Bliemer, 2018)


Measure	Fragility Dimension	Systemic Risk Drivers
Weighted Degree	Primarily parent companies, or direct subcontract award to major prime contractors. The network is dependent on forecasted demand	• Demand Uncertainty • Budget Uncertainty • Natural Disaster or Malicious Attack
Betweenness	Composed of "bridge suppliers," this model moves to the first tier of the prime contractor supplier spend. As an effect, these are primarily parent suppliers or familiar sources of supply for generic material (electronic components, fasteners)	• Foreign Dependence • Single Sources of Supply
Closeness	Relatively high overlap of closeness and weighted degree indicates that the network's agility or speed depends on large tier suppliers. Respective capabilities and capacities should facilitate shorter paths through the network	• Limited production capacity • Foreign Dependence • Natural Disaster or Malicious Attack
PageRank	The PageRank algorithm consistently highlights influential suppliers outside of the top spend.	• Obsolete Items • Financial Viability of Suppliers • Sole sourcing • Loss of skill or equipment
EigenCentrality	They are highly coupled or connected suppliers within the network; their dependencies cross over programs, procuring agencies, and even commodities.	• Limited production capacity • Foreign Dependence • Loss of skill or equipment • Financial viability • Sole source • Natural Disaster or Malicious Attack

Visualizations of Systemic Risk
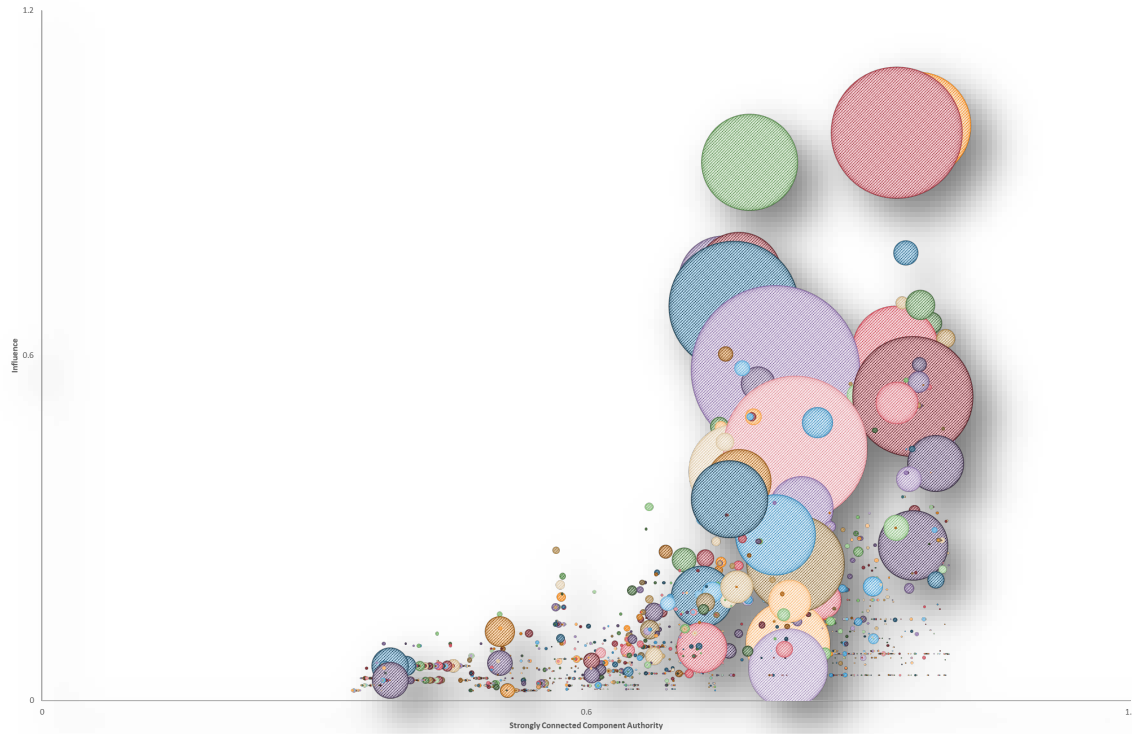
FY20 – Aircraft NAICs Holistic Base View
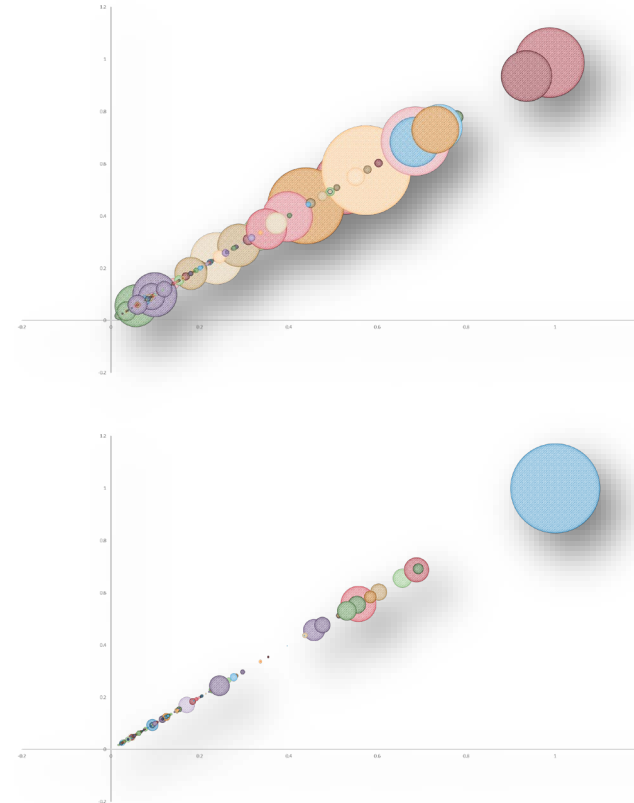
FY20 – Aircraft NAICs Supplier Risk Characterization

FY20 – Aircraft NAICs Module Based Risk Characterization

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Mapping to Traditional Risk

Traditional Risk Area (GAO)	Traditional Approaches	Concern	Pf Measures (Likelihood)	Cf Measures (Severity)
Financial Viability of Suppliers	Monitor – Monitor DUNs data as available	Shrinking defense industrial base, inconsistent demand forecasting	DUNS Trend (6-month, 12 month) – Couple with community measures, the financial viability of the community	Highest betweenness levels within a community
Sole Source	Monitor – Quantitative at the program level	Single points of failure	Closeness centrality, ability to share demand	Highest Eigenvector measure within a network
Limited Production Capacity	Avoid - Qualitative, supplier RFPs	Inability to ramp quickly	Trend analysis supplier CAGR (increasing) Highest Eigenvector measure within a network; within a commodity	Highest Eigenvector measure within a network; within a commodity
Facility Damage by Disaster	Monitor - Quantitative concerning risk areas, qualitative regarding the impact	The failure mode of sole-source	Natural disaster probabilities/distributions	Supplier Geolocation – Number of programs/primes impacted Highest Eigenvector measure within a network; within a commodity
Loss of Skill or Equipment	Accept – Difficult to quantify. Highly variable by program	Lack of manufacturing expertise and DIB investment funding	Trend analysis supplier CAGR (decreasing)	Highest Eigenvector measure within a network; within a commodity
Foreign Dependence	Mitigate - Quantitively at the prime level, qualitative at the subcontract level	Component dependencies external to the US	DUNS Trend (6-month, 12 month) – Couple with community measures, the financial viability of the community, commercial market share	Parent DUNS, Highest Eigenvector measure within a network; within a commodity

United States Government Accountability Office. (2018). *Integrating Existing Supplier Data and Addressing Workforce Challenges Could Improve Risk Analysis.* Washington, D.C.: GAO-18-435.

Summary

- Systemic risk is quantified using centrality measures
  - Identifies the most critical nodes (suppliers) within the network
  - A supplier with more influence carries more negative network impact in the event of disruption and is more systemically risky

- Defense Industrial Base fragility is quantified using community measures
  - Identifies communities with more significant overall systemic dependencies
  - Illustrates vulnerability within the supply chain network

- Imbalance represents disproportional levels of both risk and fragility in both specific commodities and suppliers
  - Single sources of supply, limited competition options

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Abstract

- This research quantifies fragility within the United States Defense Industrial Base (DIB) and translates it into supplier risk.
    - It identifies systemically critical suppliers, where criticality is characterized in terms of the supplier either being highly coupled within the industrial base, operating in a limited competition space or owning a disproportionately large market share within a specific commodity.

- Each of these properties is quantified using centrality and community detection methods.
    - By correctly assessing critical suppliers in the defense base, it allows for a methodical approach to preemptively addressing standard failure modes that typically result in material disruptions.

- Quantifying fragility in supply chains based on systemic centrality and communities is a novel effort.
    - Direct application of this process within the DIB fundamentally approaches assessing our supply base resiliency in a completely different manner.

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USG Value Proposition

Illuminates Foreign Reliance
Provides insight on foreign dependencies at both the subcontract award level as well as providing any foreign parent relations; detailed by spend, program, and commodity supported

01

02
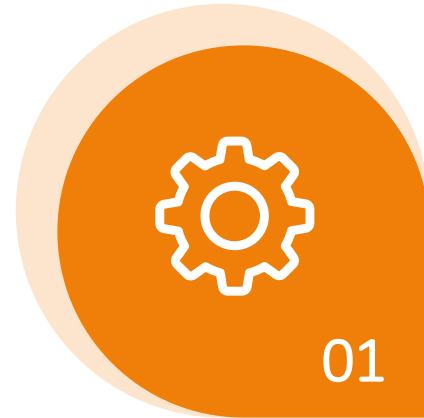
Risk Characterization
Facilitates a risk-based framework for identifying critical suppliers, commodities, or industries.

04
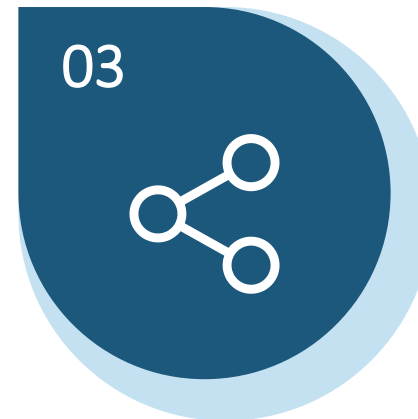
Informs Base Development
Supports prioritization of development spending, improve effectiveness of direct investments in the lower tier of the DIB via DPA Title III, ManTech, etc.

03

Decoupling Critical Assets
Conveys the coupling of weapon systems and subsystems by supplier; this insight supports strategic MRA/TRA engagements or dual-source development.

Supply chain risk framework

Macro forces driving risk into defense acquisition create diverse impacts

ISSUE	IMPACTS			Quantify
	FIRST TIER SUPPLIER	PRIME	USG	**Fragility Measure**
Uncertainty in spending	Compelled to invest outside of defense, consolidate	Challenge's affordability and supply base agility	Increased "bull whip" effect, systemic material shortages	Closeness
Decline of U.S. manufacturing capability and capacity	Lower defense capability investment and innovation	Capacity constrained supply market	Erosion of U.S-based infrastructure	Eigenvector
USG business practices	High barriers to market entry	Reduced advanced technology suppliers	Tightly coupled network of critical suppliers	Betweenness
Foreign industrial policies	Competitive disadvantages, increased M/A activity	Increased risk of foreign supply dependencies	Foreign dependency, product security risk	Eigenvector + Commercial Presence + Parent DUNS
HOW CAN WE HELP?	**Identify fragility by commodity**	**Build resiliency in our supply base**	**Influence DIB investments aimed at strengthening**	**Map to traditional Pf measures (GAO,DoD)**

Example Network Visualizations
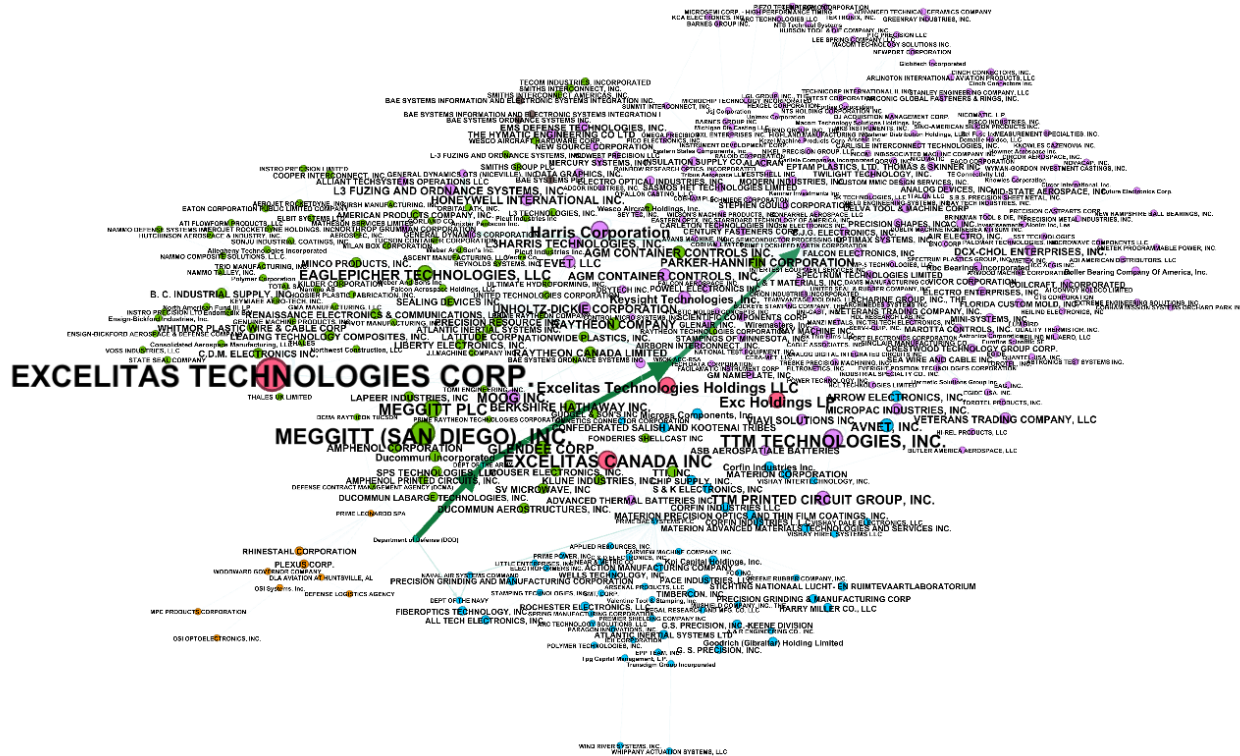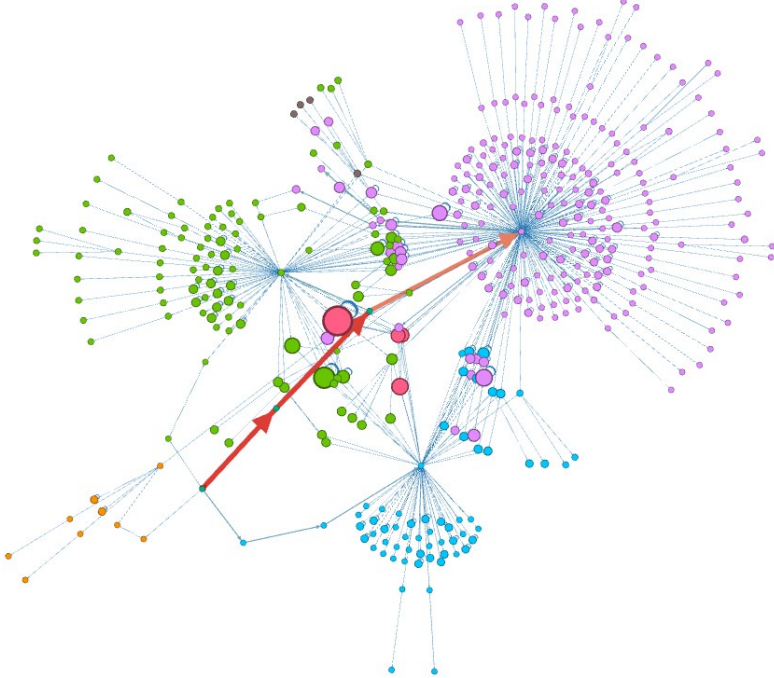
Above: Network Map reflects the aggregated supplier spend of incorporated programs along with the dependencies representing material flow

Above: Network Map with supplier names, illustrating the complexity and density of the network. Larger text indicates supplier criticality

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Criticality Assessments

Betweenness

|	
AMPHENOL CORPORATION	17
BAE SYSTEMS PLC	21
BERKSHIRE HATHAWAY INC.	39
Corfin Industries Inc.	11
Ducommun Incorporated	17
HONEYWELL INTERNATIONAL INC.	14
MATERION CORPORATION	11
Nammo AS	18
SMITHS GROUP PLC	21
VISHAY INTERTECHNOLOGY, INC.	14

Eigenvector

EXCELITAS TECHNOLOGIES CORP.	1
MEGGITT (SAN DIEGO), INC.	0.660834
TTM TECHNOLOGIES, INC.	0.490661
EXCELITAS CANADA INC	0.475433
MEGGITT PLC	0.429083
Harris Corporation	0.420989
Exc Holdings LP	0.376692
Excelitas Technologies Holdings LLC	0.376692
EAGLEPICHER TECHNOLOGIES, LLC	0.349024
MOOG INC.	0.322545
GLENDEE CORP.	0.322545

Authority

Excelitas Technologies Holdings LLC	0.09057
BERKSHIRE HATHAWAY INC.	0.090141
MOOG INC.	0.081135
EAGLEPICHER TECHNOLOGIES, LLC	0.081127
DRYTECH INC.	0.080745
UNITED TECHNOLOGIES CORPORATION	0.080745
SMITHS GROUP PLC	0.080745
ULTIMATE HYDROFORMING, INC.	0.080745
AGM CONTAINER CONTROLS, INC.	0.080745
L3HARRIS TECHNOLOGIES, INC.	0.080745
NORTHROP GRUMMAN CORPORATION	0.080745
PARKER-HANNIFIN CORPORATION	0.080745
BAE SYSTEMS PLC	0.080745
Picut Industries Inc.	0.080745
RAYTHEON COMPANY	0.080745
GENERAL DYNAMICS CORPORATION	0.080745
TEVET, LLC	0.080745
HONEYWELL INTERNATIONAL INC.	0.080745
UNHOLTZ-DICKIE CORPORATION	0.080745
Keysight Technologies, Inc.	0.080745
Wesco Aircraft Holdings, Inc.	0.080745
KILDER CORPORATION	0.080745
L3 TECHNOLOGIES, INC.	0.080745

Weighted Degree

GENERAL DYNAMICS CORPORATION
NORTHROP GRUMMAN CORPORATION
MOOG INC.
VETERANS TRADING COMPANY, LLC
Exc Holdings LP
UNITED TECHNOLOGIES CORPORATION
TTM TECHNOLOGIES, INC.
L3HARRIS TECHNOLOGIES, INC.
MAROTTA CONTROLS, INC.
Transdigm Group Incorporated
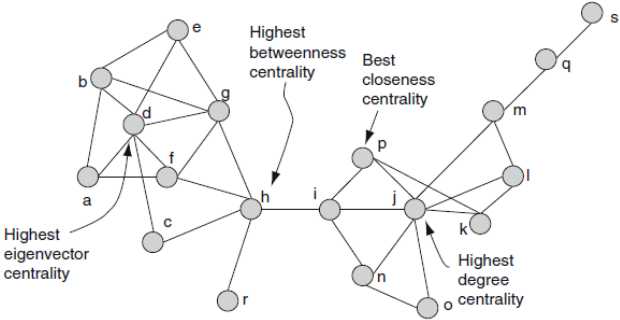
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