Quantitative Capability Delivery Increments: A Novel Approach for Assessing DoD Network Capability

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This Briefing

- **Summarizes paper presented at Infotech@Aerospace conference**
  - Inform community about availability of tools, methods and approaches
  - Get feedback from community researchers working similar problems
- **Focuses on a flexible approach for applying the QCDI Demand model to assess the adequacy of network capability**
  - Means of identifying major shortfalls in supply & assessing alternatives
  - Methods that can be used to enable Network Mission Assurance analysis
- **Assumes**
  - Familiarity with the QCDI Demand Model, described in draft ICCRTS paper, June 2010
- **Describes**
  - Objectives & supply construct
  - Methods for estimating capability supply
  - Overview of assessment approach
  - Illustrative applications

QCDI Supply Model
Objective & Basic Construct

- **Objective: Develop methodology for estimating supply of net centric capability**
  - Suitable for comparison with demand at the unit level
  - Feasible to execute across all units, timeframes, and programs
  - Flexibility to balance quality of estimate with data availability & effort
- **Basic supply construct:**
  - Sets of users (units) are provided capability by programs
  - Programs provide capability via program components (e.g., devices, service instances, etc.) with quantifiable performance characteristics
  - Program component performance can be estimated and aggregated at varied levels of sophistication that can account for a range of factors depending on the data available & quality of estimate needed
  - Unit supply is estimated by aggregating over relevant components in each program providing capability, then over programs

Output Views for Steps in Methodology

Supply for Unit Type and Time Frame

From Program, Unit and Architecture Data

Component Fielding to Units

	2012			2016			2020		
	C_1	C_2	C_3	C_1	C_2	C_3	C_1	C_2	C_3
MEB (USMC)	0	0	0	0	0	0	0	0	0
HBCT (USA)	330	200	268	495	302	403	744	455	606
BSTB (USA)	0	0	0	0	0	0	0	0	0
CAB (USA)	122	74	99	183	111	149	275	167	224
HHC CAB (USA)	14	9	12	21	14	18	32	21	27
RC CAB (USA)	72	43	58	108	65	87	162	98	131

Component Mapping to Demand Type

	C_1	C_2	C_3
LOS	✓	✓	
BLOS			
Indirect			✓

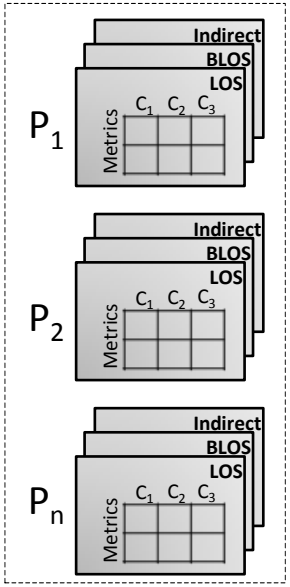
Component Performance Metrics

	C_1	C_2	C_3
Data Rate	600 kbps	600 kbps	1400 kbps
Voice DR	16 kbps	16 kbps	16 kbps
Protected DR	0 kbps	0 kbps	0 kbps

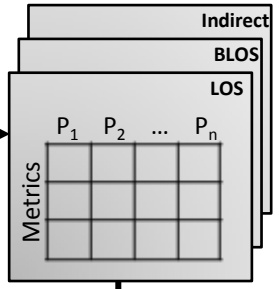
Component Fielding by Demand Type

		C_1	C_2	C_3
Number of Components	LOS	330	200	
	BLOS			
	Indirect			268

Component Supply



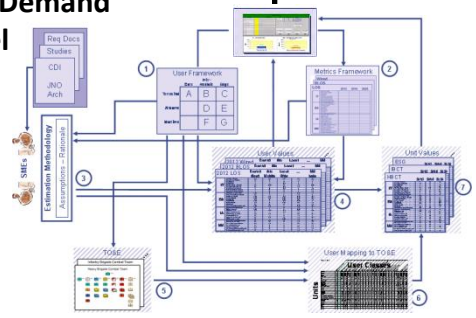
Program Supply



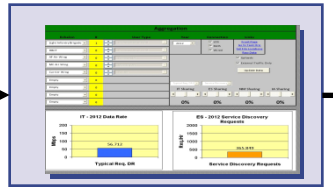
Unit Supply

	Total	OTM
M1		
M2		
…		
M3		

QCDI Demand Model



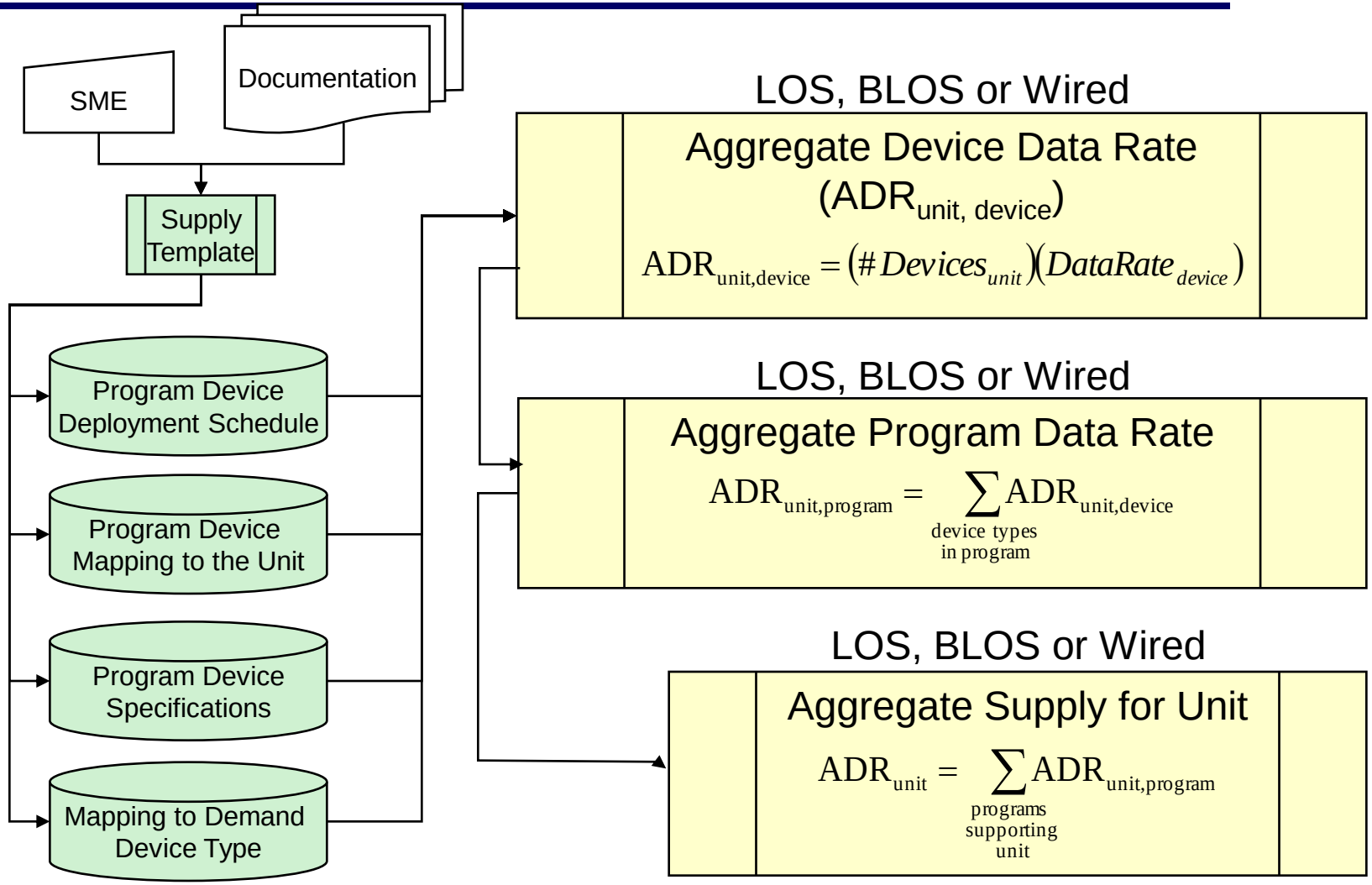
QCDI Demand Exploration Tool



Analyst

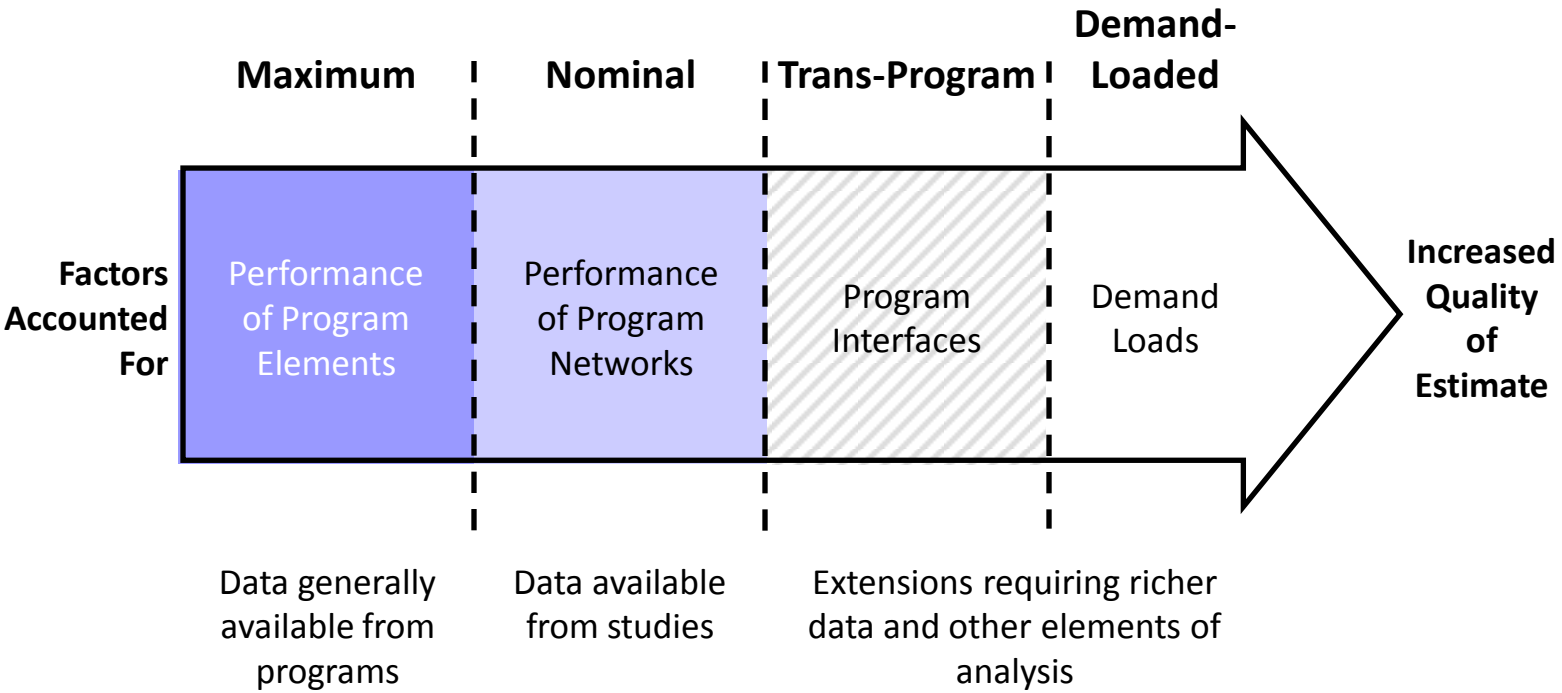
Decision Maker

Program Supply Calculations for a Major Unit Aggregate Data Rate Metric



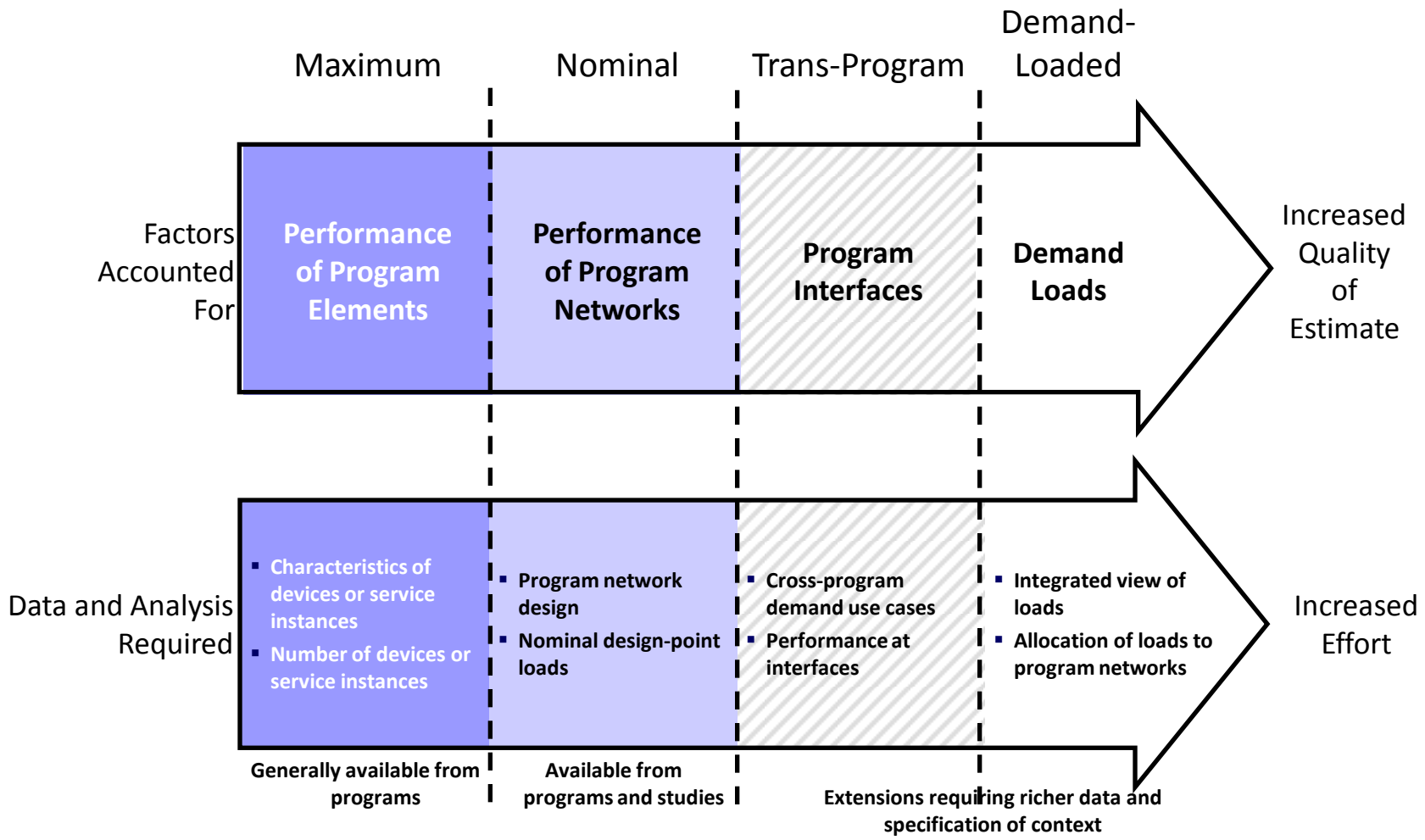
Key challenge is accounting for interactions among elements

Incremental Maturity Levels for Supply Capability Estimates



Additional assumptions or analysis required as device, program, and demand interactions are progressively considered

Incremental Maturity Levels for Supply Capability Estimates



Illustrative Calculations for Levels 1 & 2

Level 1 Supply Estimate

- **Assumptions**
  - Radio terminals have transmit/receive capability of 0.6 Mbps per channel when communicating point to point
  - Notional program has 1-, 2-, and 4-channel radios with LOS capabilities
  - Fielding as indicated in table below

	Device 1 Chan	Device 2 Chan	Device 4 Chan
Data rate per radio (Mbps)	0.6	1.2	2.4
Radios in unit	36	375	30
Data rate to unit (Mbps)	**21.6**	**450.0**	**72.0**

Level 1 Estimated Supply: 543.6 Mbps

Level 2 Supply Estimate

- **Assumptions**
  - When employed in the field, radios are configured in subnets in which, on average, 30 nodes share 200 kbps of subnet capacity (≈ 0.007 Mbps/node)
  - 2- and 4-channel radios have half their channels configured for voice
  - Each channel treated as a separate radio for subnet participation purposes

	Device 1 Chan	Device 2 Chan	Device 3 Chan
Data rate per radio (Mbps)	0.007	0.007	0.014
Radios in unit	36	375	30
Data rate to unit (Mbps)	**0.25**	**2.63**	**0.42**

Level 2 Estimated Supply: 3.30 Mbps

Factors Accounted for at Levels 3 & 4

- **Level 3: Interactions among programs**
  - Constraints due to interacting programs; e.g. Impact of limitations in satellite capacity on potential capacity of the terminal or vice versa
  - Minimum capability of systems in the chain may dictate overall performance
- **Level 4: Impact of demand itself on the supply network**
  - The impact of demand reflected as a load on the supply networks and devices;
    - Often different from design loads assumed by program offices
  - The effects of other programs or users that are not explicitly part of the of the demand or supply being studied
    - E.g. , other users may be sharing satellite bandwidth
  - Other effects in which the nature and structure of demand affects of the ability of the program to provision
    - E.g., only a portion of demand can be satisfied by broadcast capability

Assessment Approach (1)

- **Define the issue**
  - Existing, programmed or proposed systems of concern
  - Operation, mission or forces potentially effected
- **Identify the relevant QCDI dimensions**
  - Functional domain(s)
  - Device type(s) and key demand metric(s)
  - Users and units to be supported
- **Characterize the supply architecture(s) at issue in terms of additional dimensions of the QCDI demand framework; e.g.**
  - The types and numbers of devices provided,
  - Relevant modes of operation
  - Use or configuration to support a typical unit.

Assessment Approach (2)

- **Estimate the aggregate supply provided by the mix of programs to the relevant units**
- **Determine the appropriate demand from the QCDI model to serve as a point of reference for the assessment**
  - In some cases, it may be necessary to parse the demand of users further to map portions of demand (e.g., from subsets of users) to the systems and programs in the architecture.
- **Compare aggregate supply with aggregate demand for each of the metrics chosen**
  - Drill down to greater resolution as necessary.
- **Repeat to explore alternative solutions for filling gaps**
  - Conduct sensitivity analysis.

Illustrative Applications Described in Paper

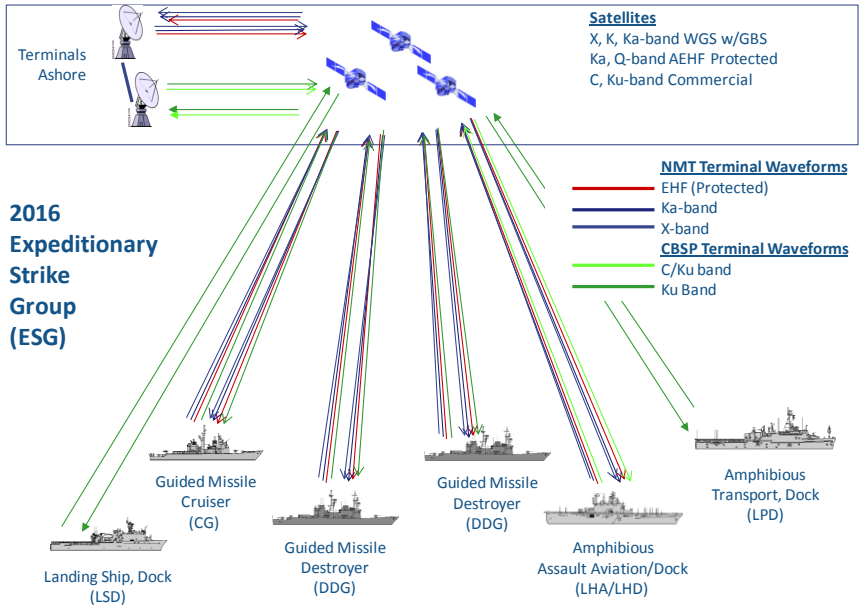
- **Incremental tactical radios capability for major ground unit**
  - LOS data comms capability supplied to a specific class of users by a radio program
  - LOS data comms capability supplied to OTM users in an HBCT by a radio program
  - All data comms capability provided to an HBCT by a radio program plus a program providing backbone capabilities

- **Alternative Satellite communication capability for a maritime JTF**
  - Base case: Satellite terminals providing access to protected and unprotected SATCOM
  - Alternative 1: Addition of leased commercial SATCOM
  - Alternative 2: Utilization of broadcast capability
  - Alternative 3: Additional unprotected military SATCOM capacity

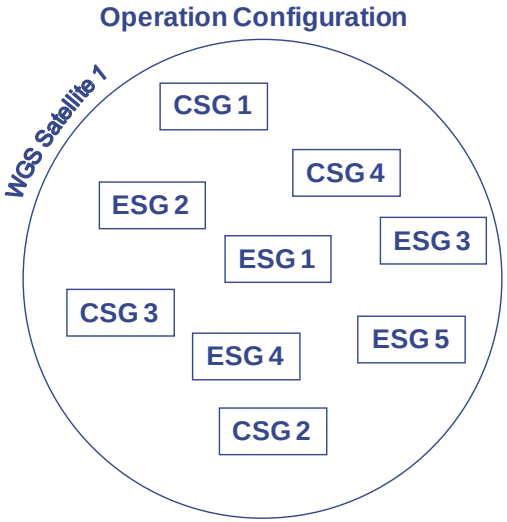
Maritime Situation

Problem Profile

Programs	Point-to-point military satellite capabilities with and without jamming resistance, commercial point-to-point satellite capabilities and satellite broadcast capability
Devices	Mix of configurable multimode satellite terminals and antenna groups that vary with the type of ship supported
Type device demand	Indirect demand
Metrics	Typical data rate and protected communications data rate
User classes	Command Post
Unit structure	JTF comprised of 4 Carrier Strike Groups and 5 Expeditionary Strike Groups, each of which includes both large and small ships
Timeframe	2016



JTF Comprised of Nine Strike Groups



Maritime Assessment: Base Case

- **Assumptions**
  - Ships have one DOD SATCOM terminal providing access to two satellites
    - One providing unprotected communications
    - One providing protected communications (high robustness and encryption)
  - Capability available to ship limited by either terminal or SATCOM capacities (whichever is smaller)
  - SATCOM capacities:
    - Protected: 250 Mbps
    - Unprotected: 214 Mbps
  - Terminal capacity: 517 Mbps

- **Calculations**
  - Protected supplied first
    - SATCOM sufficient for 1/3 of demand
    - Fully utilized
  - Remainder available for unprotected
    - 267 Mbps terminal capacity remains
    - Only 214 Mbps SATCOM capacity available

	Unprotected	Protected
Terminal Supply (Mbps)	267	250
Satellite Supply (Mbps)	214	250
Constrained Supply (Mbps)	**214**	**250**
Demand (Mbps)	1000	750
Percent Demand Satisfied	**21%**	**33%**

Impact of Adding Commercial Leases, Broadcast, and Additional Military SATCOM Capacity

- **Assumptions**
  - Terminals and leased commercial SATCOM added to JTF ships
  - The capacity of an additional military satellite is available to the JTF
  - Broadcast capability of military satellite utilized to deliver common-use information to JTF; broadcast receiver terminals added
- **Calculations**
  - Commercial terminals provide additional 50 Mbps to supply of unprotected comms
  - Broadcast capability uses 14 Mbps of military SATCOM capacity to satisfy 125 Mbps of demand
  - Additional military satellite increases available SATCOM supply by 214 Mbps

	Base Case Unprotect Pt-pt	Military Unprotect Pt-Pt	Commercial Leases Pt-Pt	Total Unprotect Pt-Pt	Total unprotect w/BC
Terminal Supply (Mbps)	267	267	540	807	1257
Satellite Supply (Mbps)	214	414	50	464	478
Constrained Supply (Mbps)	**214**	**267**	**50**	**317**	**442**
Demand (Mbps)	1000			875	1000
Percent Demand Satisfied	21%			**36%**	**44%**

Notes:

- Supply now terminal-constrained; full benefits of satellite investment not realized without terminal investment
- Effects such as this only picked up with portfolio-level analysis

Next Steps

- **This methodology is being evolved and matured along with the demand model and tool as well as the NMA Theory, methodology and tools**
  - Applied to a wide range of problems of varying complexity
  - Proven to be extremely adaptable to both problems and resources
- **More research and engineering analysis is needed to achieve the highest level in the estimation maturity model,**
  - To reflect the full impact of the underlying information architecture
- **An explicit methodology is being developed to parse QCDI demand estimates into requirements for the exchange of information**
  - Among nodes that characterize a force conducting a mission
- **Simple network design tools are being used to rapidly reflect the impact of these requirements in the analysis**
  - As loads on a supporting system architecture comprised of multiple programs
- **The results of this work will be presented in subsequent papers**
  - After those already mentioned

Other Venues for Community Outreach

- **InfoTech @ Aerospace (AIAA) (April 20-22, Atlanta)**
  - *Quantitative Capability Delivery Increments: An Approach for Assessing DoD Network Capability Against Projected Needs*
- **ICCRTS (US DoD CCRP) (June 22-24, Santa Monica)**
  - *Quantitative Capability Delivery Increments: A Novel Approach for Estimating and Future DoD Network Needs*
- **MORS Symposium (June 2010, Quantico)**
  - *Assessing Operational Risk Arising from Network Vulnerability*
- **IEEE Mission Assurance: Tools, Techniques, and Methodologies (August 2010, Minneapolis)**
  - *Network Mission Assurance Overview*
- **MILCOM (Oct/Nov 2010, San Jose, CA)**
  - *Estimating Mission Risk from Network Vulnerabilities*

Network Mission Assurance: Assessing the Mission Impact of Network Capability and Capability Gaps

Why a Mission Assurance Framework for End-to-End Network Analysis?

Need: Quantitative Mechanism to Link Performance of Planned Network Architectures to Mission Outcomes

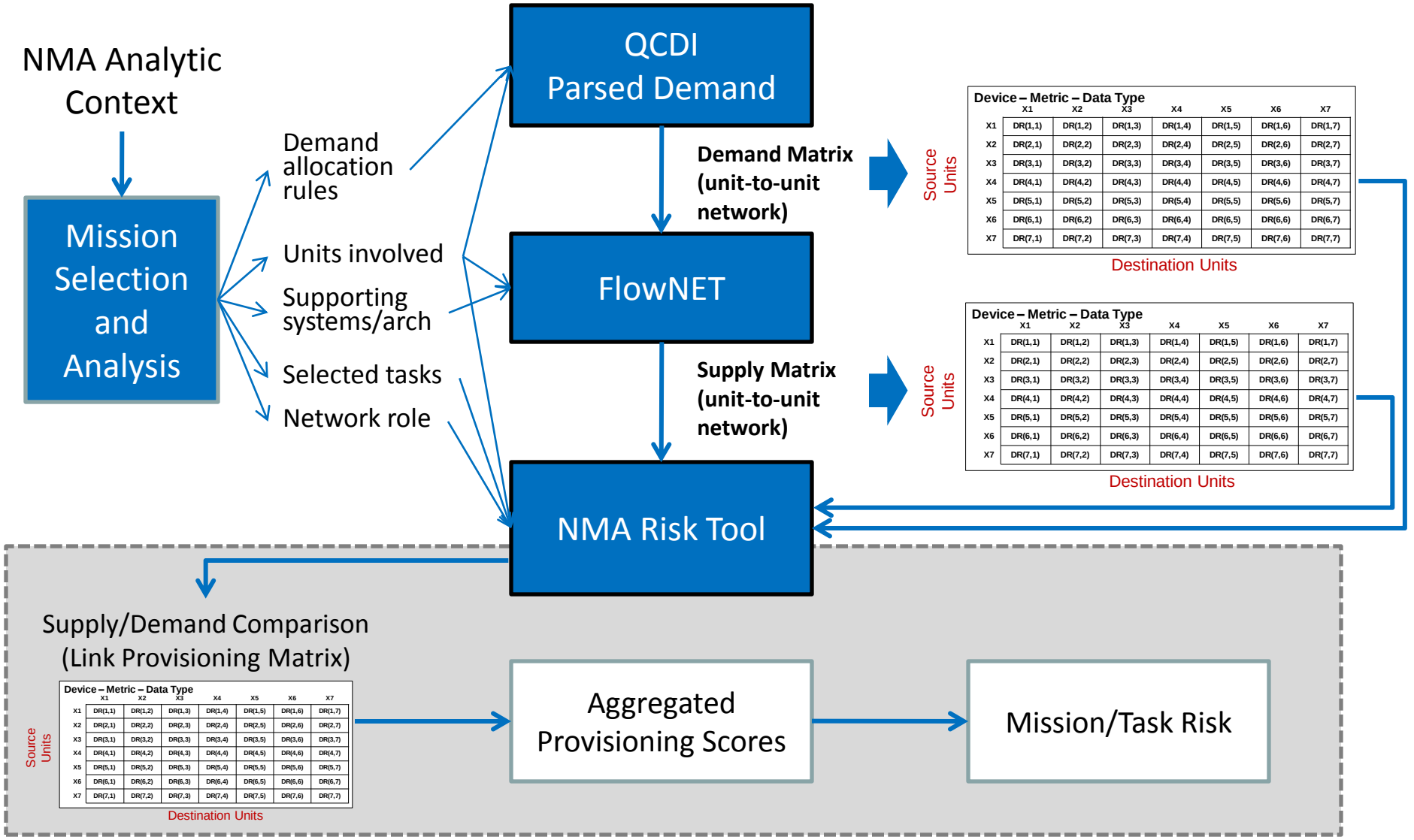
- What are the threats to the network and their quantitative impact on the network?
  - Enemy action
  - Environmental
  - User behavior
- What are the mission impacts of network attacks or failures?
  - Not all network degradation impacts the mission
  - However, network problems can impact critical tasks
- What are the benefits of various mitigation strategies/solutions?
  - Understand the impact of options at the critical task level
  - Present quantitative, repeatable, apples-to-apples comparisons

Solution: Leverage previous OSD/Service investment in a family of tools and techniques developed for quantitative analysis of Net-Centric Architectures/Programs

Summary of Previous Work Relating Mission Needs to Network Performance

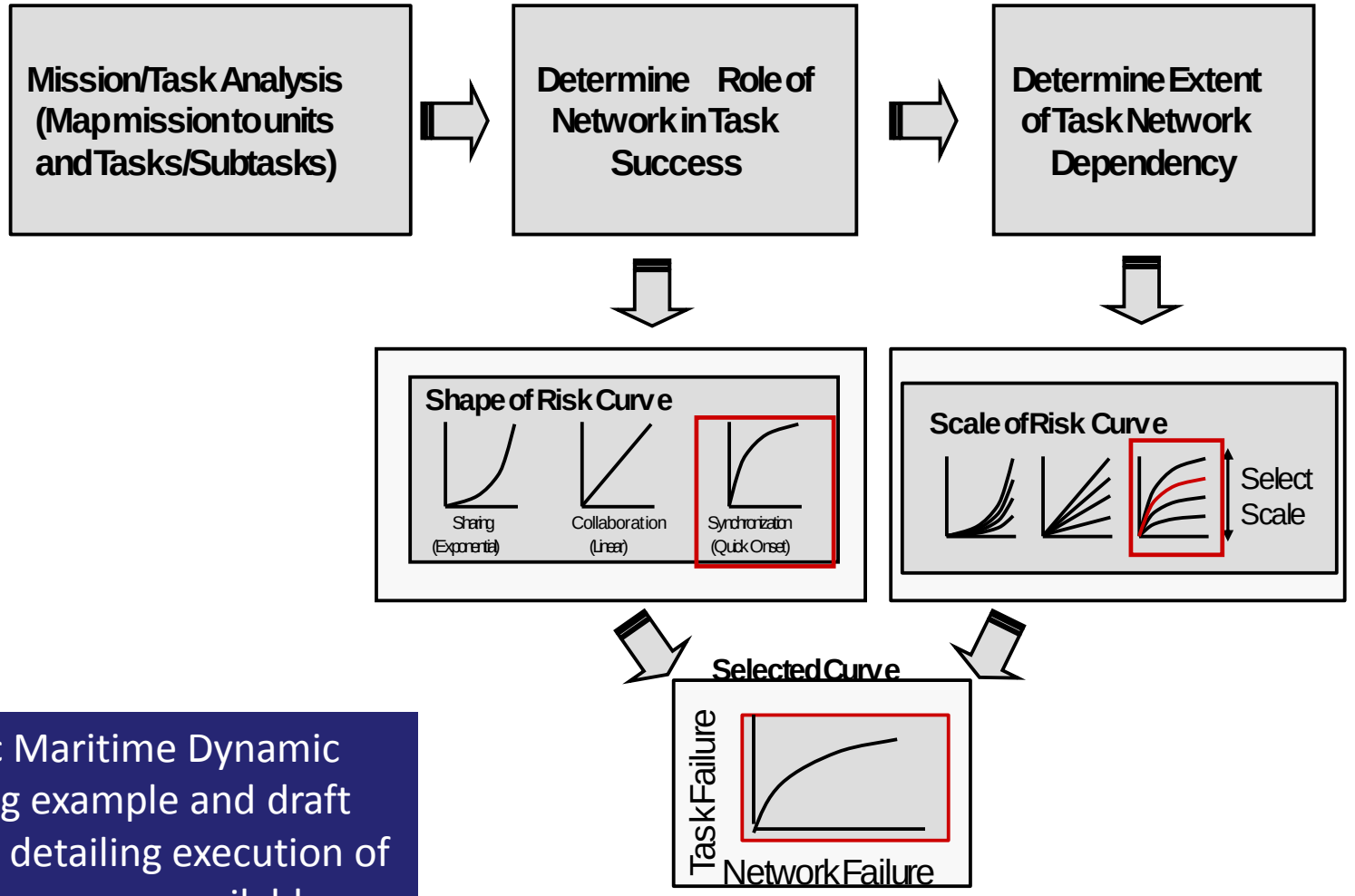
- **Recent work in DoD has established general frameworks to relate critical "enablers" to mission outcomes**
  - Critical Infrastructure Protection activities have identified infrastructure components needed to accomplish high-level missions
  - Recent OSD Network Mission Assurance efforts examined network support to "Mission Essential Functions"
  - These initiatives typically examine vulnerabilities, mission implications and mitigation strategies for common user networks via a single metric (e.g. throughput)
- **Approach developed in OASD/NII work to date:**
  - Use selected CONPLAN, scenario, vignette, etc. to derive **critical tasks, units involved**, environmental considerations, and **threats**
  - Examine each critical task separately in terms of type of C2 and network support required for task performance
  - Use Joint and Service doctrine/TTPs/TACMEMO/etc. to determine nature of task dependency on network support
  - Apply family of tools for end-to-end quantitative and repeatable results

NMA Tool Suite: Components and Relationships



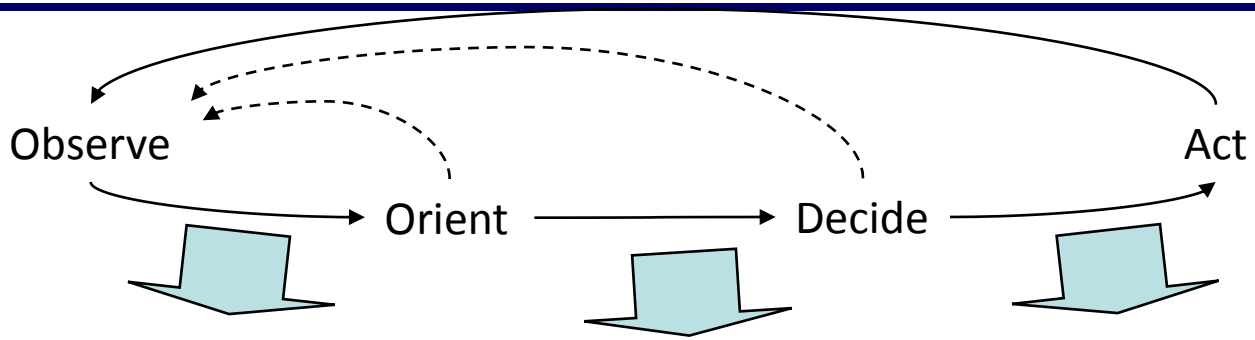
Process for Determination of Task Risk Due to Network Failure

Note: Process repeated for each mission phase, critical function, etc.

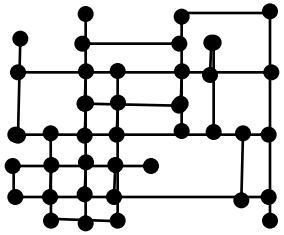


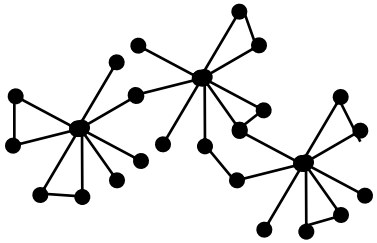
Specific Maritime Dynamic Targeting example and draft document detailing execution of this process are available

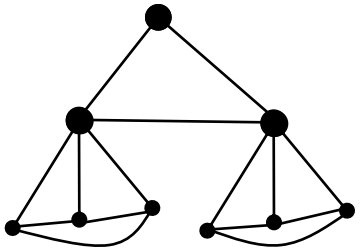
Roles of the Network in Enabling Mission Activities: Enabling Segments of Boyd's OODA Loop



Type	Information Sharing	Collaboration	Direction
Network Role	Provide access to information	Provide means for interaction	Real-time interaction and information exchange
Requirement	Path existence	Relatively short paths	Very short or direct paths
Example(s)	Flat network, random matrix	Small World, Semi-random w/preferential attachment	Deterministic hierarchal, rooted tree (for local synchronization)

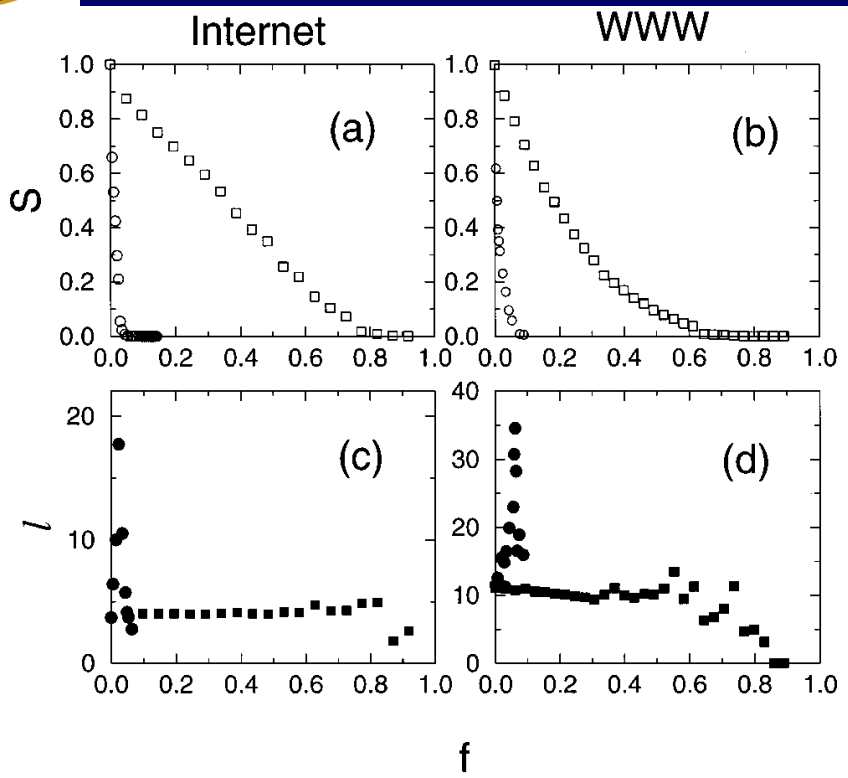






Network Decay From Node Removal

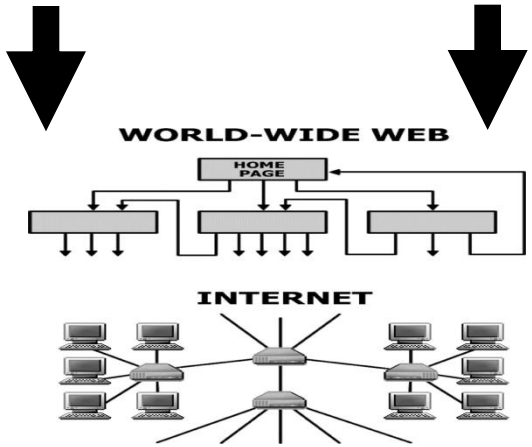
From: R. Albert and A.-L. Barabasi: Statistical mechanics of complex networks
REVIEWS OF MODERN PHYSICS, VOLUME 74, JANUARY 2002



The relative size *S* (a),(b) and average path length *l* (c),(d) of the largest cluster in two communication networks when a fraction *f* of the nodes are removed: (a),(c) Internet at the domain level, *N*=56209, k=3.93; (b),(d) subset of the World Wide Web (WWW) with *N*=5325729 and *k*=4.59. squares = random node removal; dots= preferential removal of the most connected nodes. After Albert, Jeong, and Baraba´ si (2000).

$P(k) \sim k^{-\gamma}$, γ, ~2.5

Both WWW and INTERNET have small world network characteristics, but INTERNET is closer to deterministic tree structure, and decay shows some exponential characteristics while WWW decays linearly….



However, other algorithms suggest that random and small-world networks may have similar decay [risk] curve shapes with respect to S ….

Exemplar Results from NMA Analysis (All Results Notional)

Task	Threat	Mitigation	Likelihood Task Failure	Comments
ALL	None	None	0%	Task Link Needs (assumed met in base case) Man CO-Cmd links for HUMINT Collection Man CO – Spt unit for FWD Resupply Man CO – Man CO for COIN Combat
Destroy Enemy LRFs	Jamming	None	0%	Jamming insufficient to reduce link capability below demand levels
Secure Bridge Sites	Jamming	None	25%	Peak loads push demand for some links (e.g., between maneuver companies and support units) above available supply
Secure Bridge Sites	Jamming	Fiber	25%	No mitigation: Fiber only add link capability between stationary units (e.g., HHC units and support units)
Defeat OBJ EAGLE Enemy	Jamming	None	30%	Jamming reduces capacity of wireless links connecting Man COs with support units and Bn-Bde-DIV HQs
Defeat OBJ EAGLE Enemy	Jamming	Fiber	20%	Some mitigation: Fiber enables offload of some demand between Bn-Bde-DIV level HQs and support units from tactical wireless networks

Back-up Slides

QCDI Summary

- **Versions 1 and 2 of the demand model are complete and data are available to the NC community: qcdi.rand.org (password required)**
- **Model added to OSD/CAPE M&S tools registry: *https://jds.cape.osd.mil/Default.aspx* (CAC required)**
- **Applied in approximately 20 past and current major studies/analysis efforts across DoD**
- **Additional detail and assistance with application of model and data available through the NC CPM SE&I Team**
- **Points of Contact:**
  - Jimmie G. McEver, EBR, *mcever@ebrinc.com*
  - Craig M. Burris, JHU/APL, *craig.burris@jhuapl.edu*
  - NC CPM POC: *heather.schoenborn@osd.mil*

Nature of the Problem

- **Ongoing DOD transformation to Joint net-enabled operations promises improved force agility**
  - Key to dealing with the uncertainty associated with a wide range of changing threats, missions and operations.
- **This strategy poses significant challenges for decision makers and analysts planning portfolios comprising the Joint network**
  - Identify capability gaps and determine mission implications
  - Overcome curse of dimensionality & challenge of forecasting
- **Traditional methods based on information exchange requirements have significant limitations**
  - Resource intensive and time consuming
  - Often based on the past experience of SMEs

Related NII Initiatives

- **Quantitative Descriptive Capability Increments (QCDI)**
  - Estimates demand for net centric capability
  - Assesses the supply provided by programs and systems
  - Facilitates understanding of the degree to which systems are capable of satisfying demand
- **Network Mission Assurance**
  - Estimates the mission risk associated with various levels of network capability support
  - Aims at achieving a repeatable methodology with a family of supporting tools that can be adapted to a wide range of problems
  - Models demand, supply and mission impact at low level of resolution that complements traditional methods and tools

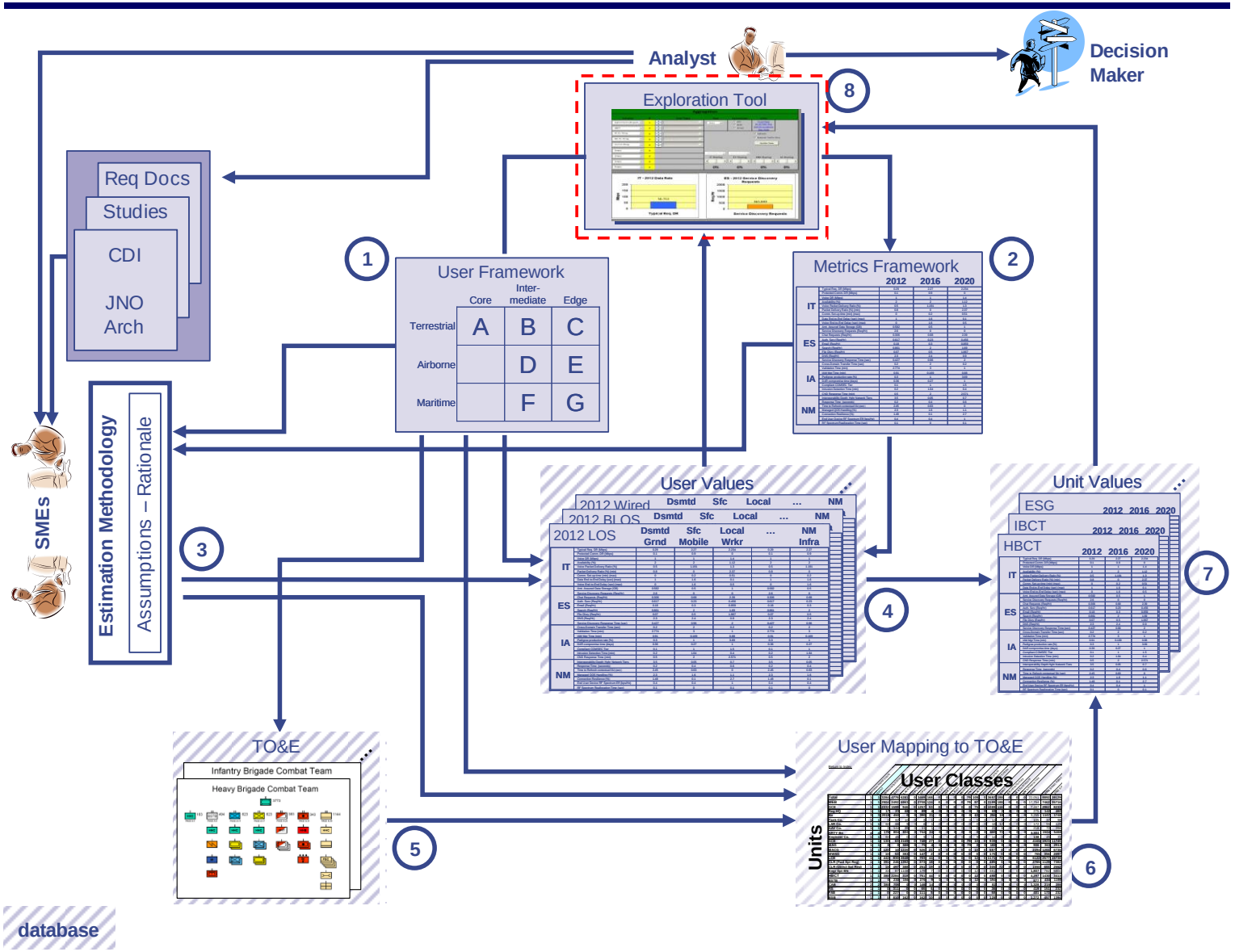
The QCDI Demand Model: Objective and Guidelines

- **Objective: Easy to use demand model that provides quantitative representation of NC needs across the entire DOD**
  - Serve as quantitative baseline for NC CPM
  - Illuminate investments likely to have greatest impact
- **Key Guidelines**
  - Focus on steps to a fully interoperable Joint network as reflected in Net Centric CDI
  - Base on specific needs of various classes of users that comprise units
  - Identify relatively small set of widely applicable metrics for 2012, 2016, 2020 CDI increments
  - Estimate values representing an 80% solution, to serve as starting point for more detailed analysis
  - Facilitate assessment of supply provided by programs

Role of Demand Devices in QCDI Demand Model

- **Key Premises**
  - Users employ devices of different types to access Joint network capabilities
  - Aggregate demand for network capability driven by trends in communication devices used to access the joint network
- **Device Types Represented in QCDI Demand**
  - **Direct Beyond-Line-of-Sight (BLOS):** User demand directly supported through a BLOS wireless device (generally direct use of a low data rate SATCOM terminal)
  - **Direct Line-of-Sight (LOS):** User demand directly supported through use of line-of-sight (LOS) wireless device
  - **Indirect:** User demand not directly supported by a wireless receiver or transmission device. This demand is aggregated with demand from other users before transport outside of local networks by either LOS or BLOS capacity

Key Elements of QCDI Demand Model



QCDI Metrics by Tier II Capability

Information Transport

- Typical Req. Data Rate (Mbps)
- Protected Comm. DR (Mbps)
- Voice DR (Mbps)
- Availability (%)
- Voice Packet Delivery Ratio (%)
- Packet Delivery Ratio (%) (min)
- Comm. Set-up time (min) (max)
- Data End-to-End Delay (sec) (max)
- Voice End-to-End Delay (sec) (max)
- Upload (%)
- External Traffic (%)

Enterprise Services

- Amt. Assured Data Storage (GB)
- Service Discovery Requests (Req/Hr)
- Chat Requests (Req/Hr)
- Auth. Serv (Req/Hr)
- Email (Req/Hr)
- Search (Req/Hr)
- File Dlvry (Req/Hr)
- DNS (Req/Hr)
- Service Discovery Response Time (sec)

Information Assurance

- Cross-Domain Transfer Time (sec)
- Validation Time (min)
- Authorization Management Time (min)
- Pedigree production rate (%)
- DAR compromise time (days)
- Compliant COMSEC Tier
- Incident Detection Time (min)
- Incident Response Time (min)

Network Management

- Interoperability Depth - Higher Network Tiers
- Response Time (sec)
- Time to Refresh contextual SA (sec)
- Priority Information Delivery Mgt (%)
- Connection Resilience (%)
- End User Device RF Spectrum Eff (bps/Hz)
- RF Spectrum Reallocation Time (sec)

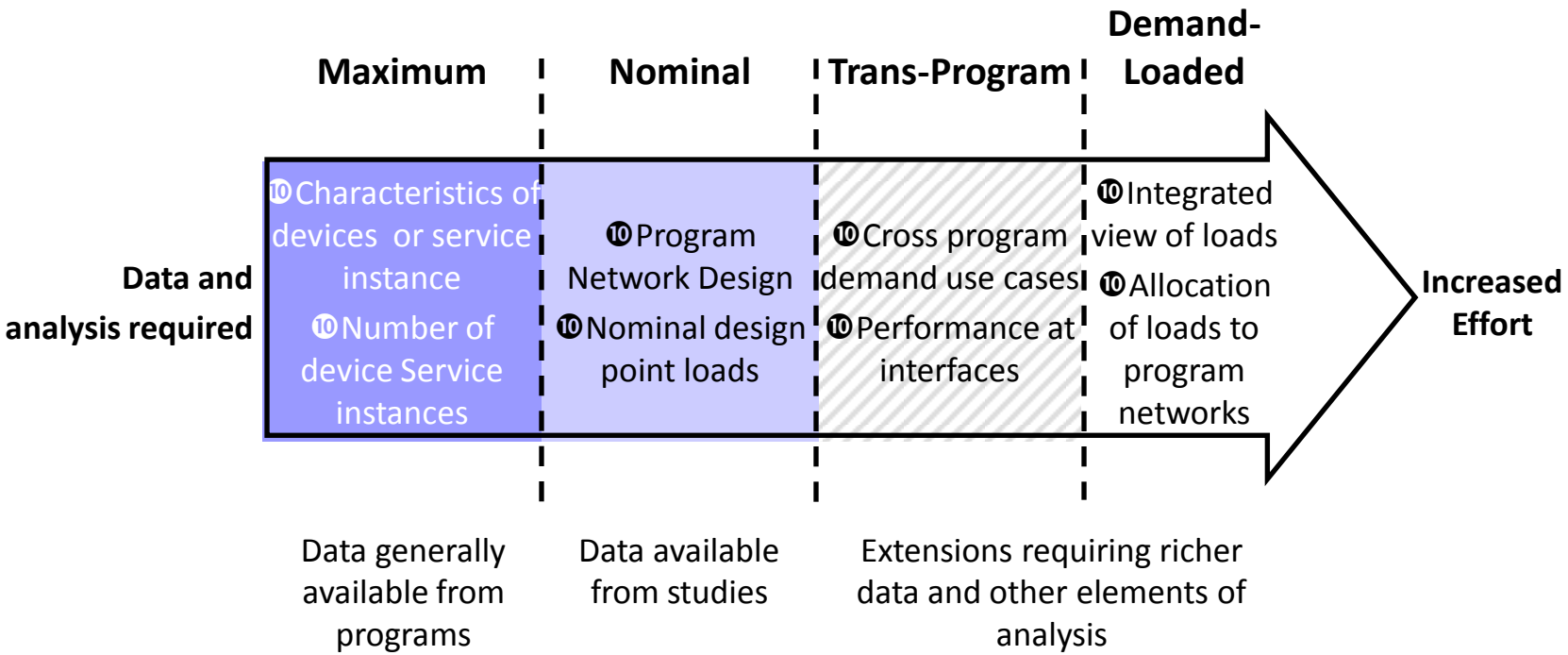
QCDI User Areas and User Classes

	Core	Intermediate		Tactical Edge	
Terrestrial/ Ground	Local Wrkr CP High USS High UAS High	Dsmtd Ground Surface Mbl Local Wrkr CP High CP Low	USS High USS Low UAS High UAS Low	Dsmtd Ground Surface Mbl Local Wrkr CP High CP Low	USS High USS Low UAS High UAS Low
Airborne		C2 Air ISR Air UAS High		LO Air Mobility Air TAC Air UAS High	
Maritime		Surface Mbl Local Wrkr CP High CP Low	USS High USS Low UAS High UAS Low	Surface Mbl Local Wrkr CP High CP Low	USS High USS Low UAS Low

All areas have Commander, Static Sensor, and ES, IA and NM Infrastructure Users

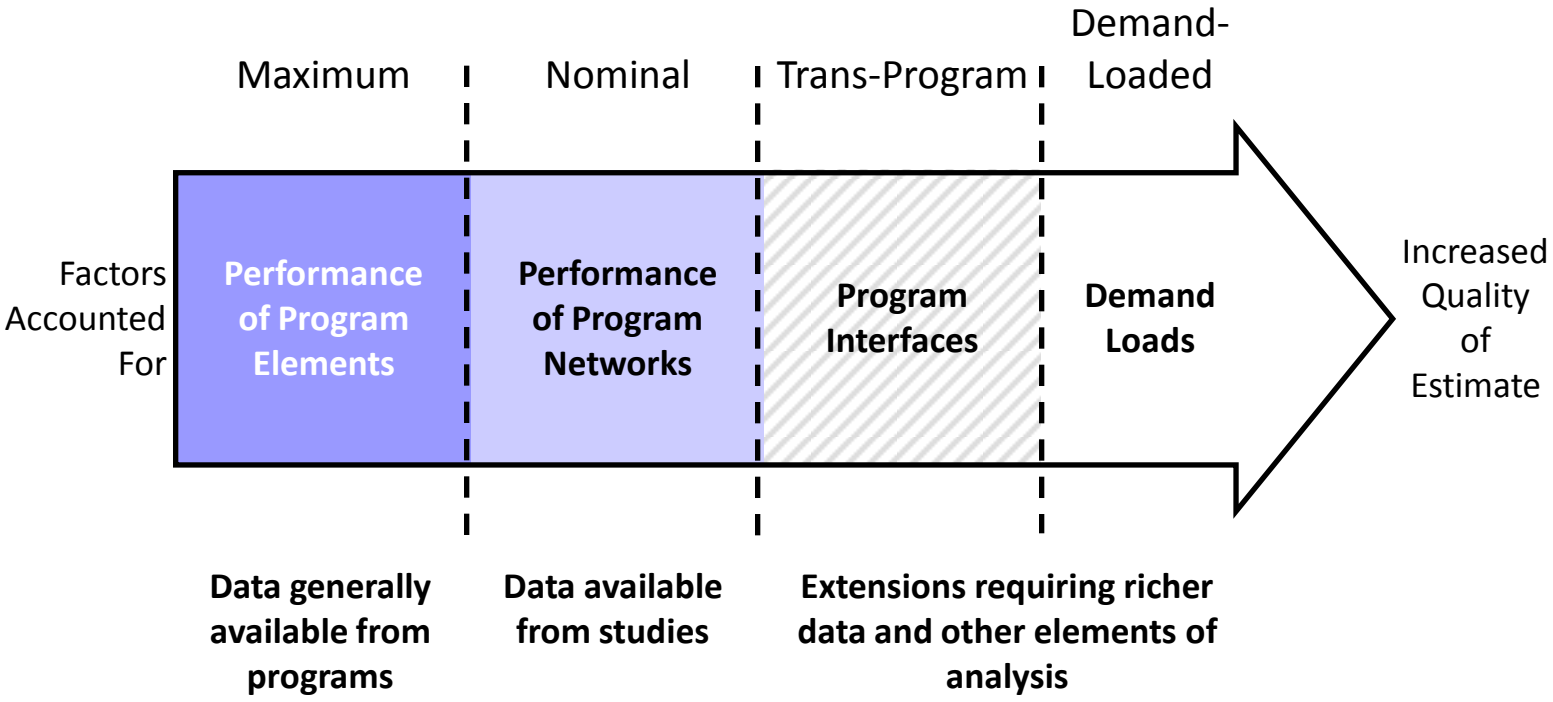
User demand aggregated to unit-level estimates: comparisons made at unit – not individual user – level

Scaling of Analysis and Data Requirements with Estimation Maturity



Additional assumptions required as device, program, and demand interactions are progressively considered

Incremental Maturity Levels for Supply Capability Estimates



*This color coding scheme is used throughout subsequent examples

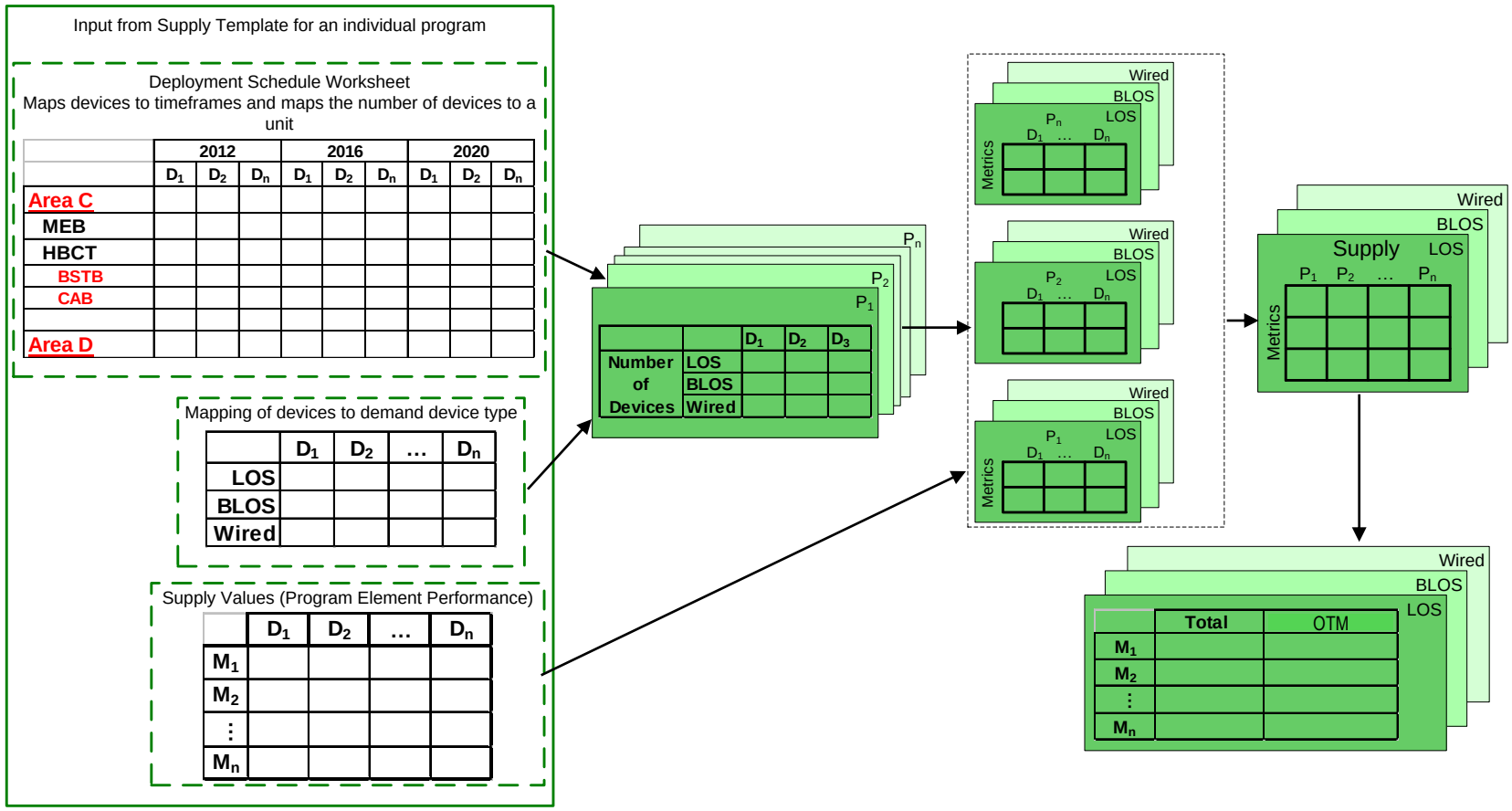
Methodological Issues Explored

- **Spectrum of data needs and analytical sophistication**
  - Relationship between effort and quality
- **Use cases consistent with the demand model for higher levels of maturity**
  - Resolution at the user vs echelon level
- **Potential role of simulations**
  - Employing PET or PET data base to different degrees

Time and resources dictated emphasis on levels 1 &2

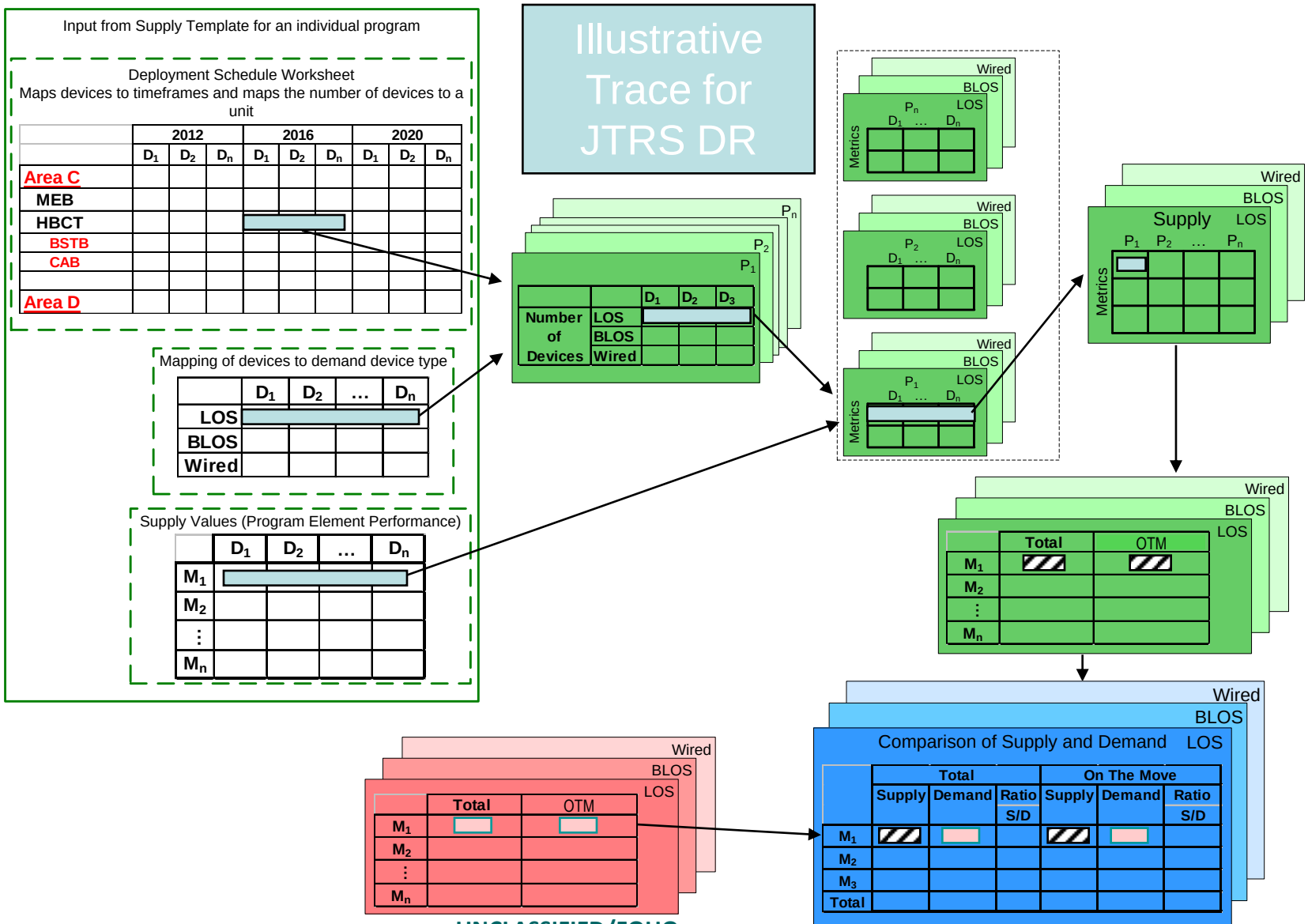
Output Views for Steps in Methodology

Supply for Unit Type and Time Frame



Output Views for Steps in Methodology

Supply v Demand for Unit Type and Time Frame



Supply v Demand for Unit Type and Time Frame

Output Views for Steps in Methodology

From Program Templates

Component Fielding to Units

components to a unit

	2012			2016			2020		
	C_1	C_2	C_n	C_1	C_2	C_n	C_1	C_2	C_n
Area C									
MEB									
HBCT									
BSTB									
CAB									
Area D									

Component Mapping to Demand Type

compontent type

	C_1	C_2	…	C_n
LOS				
BLOS				
Wired				

Component Performance Metrics

Supply Values (Program Element Performance)

	C_1	C_2	…	C_n
M_1				
M_2				
⋮				
M_n				

Component Fielding by Demand Type

		C_1	C_2	C_3
Number of Components	LOS			
	BLOS			
	Wired			

Component Supply

Wired / BLOS / LOS

Metrics: P_n C_1 … C_n

Program Supply

Wired / BLOS / LOS

Supply: P_1 P_2 … P_n

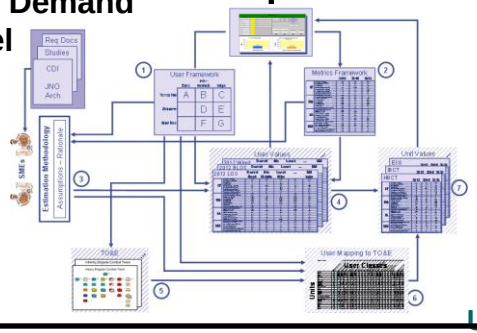
Metrics

Unit Supply

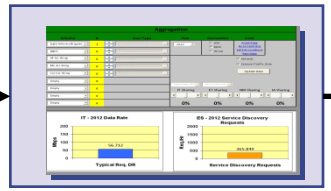
Wired / BLOS / LOS

	Total	OTM
M_1		
M_2		
⋮		
M_n		

QCDI Demand Model



QCDI Demand Exploration Tool



Analyst

Decision Maker