



# Approach to Capability-Based System-of-Systems Framework in Support of Naval Ship Design

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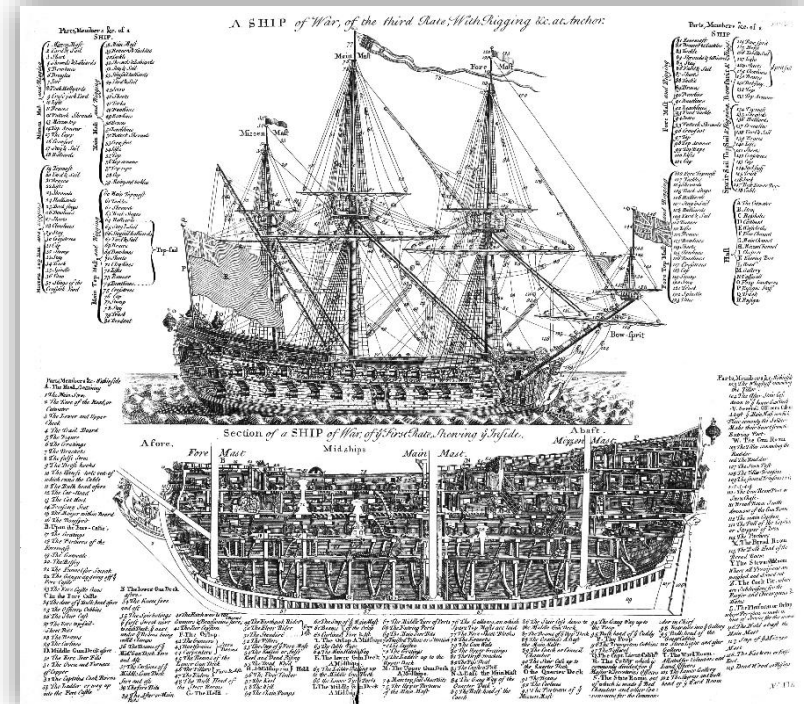
**System of Systems Engineering Collaborators Information Exchange (SoSECIE)**

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# Outline

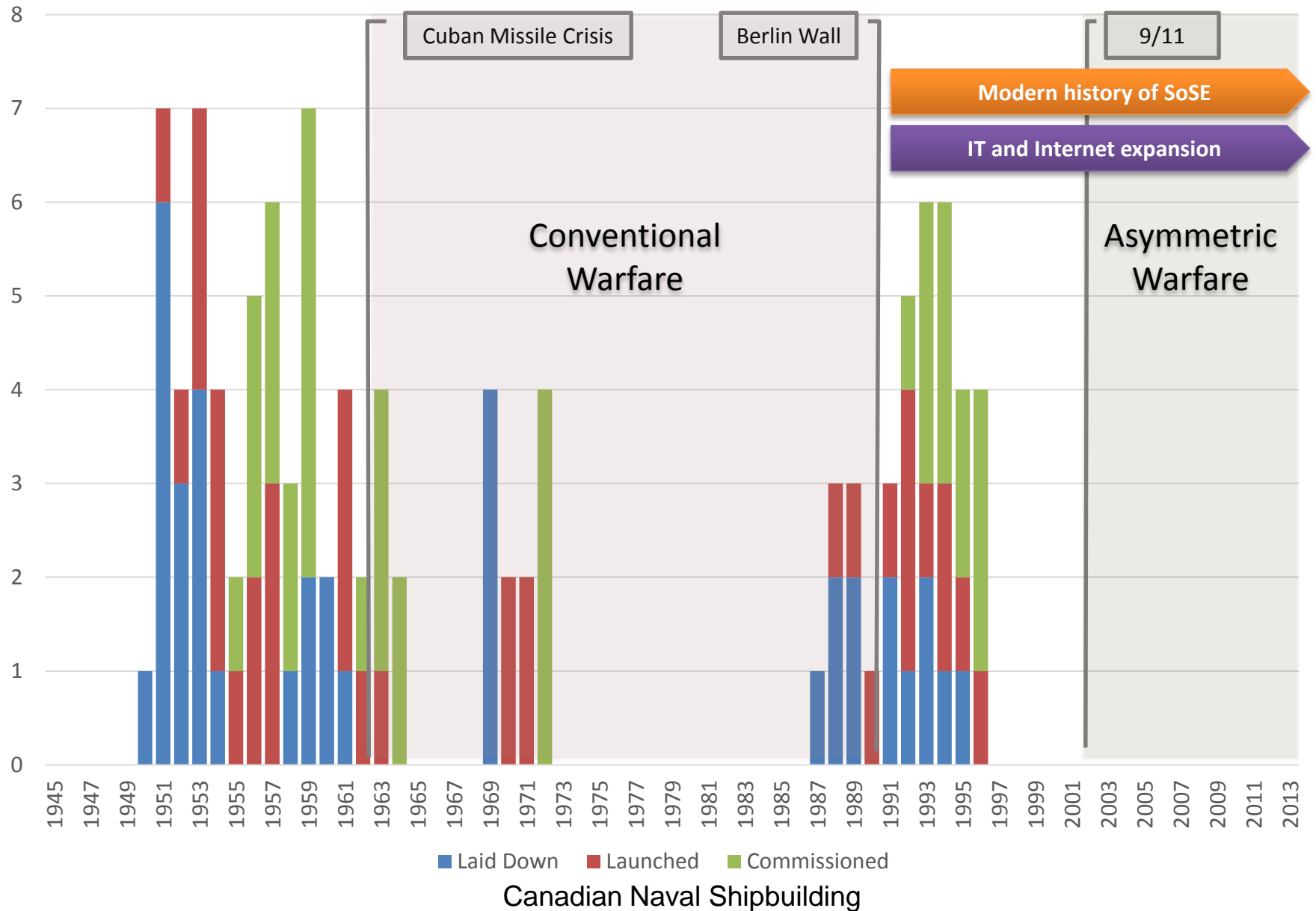
- Background and Motivation
- Benefits, Restraint and Constraint
- Definitions
- Hierarchical Decomposition
- Cross-Functional Decomposition
- Visualisation and Demonstration
- Design Paradox
- Conclusion



<http://russellclaxton.blogspot.ca/2009/08/form-and-function-3.html>

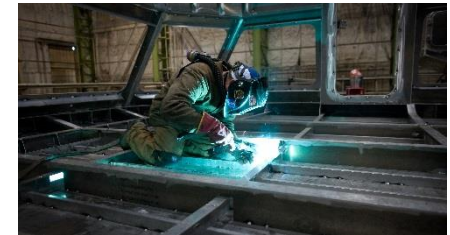
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# Historical Background



# Problem Definition

- Prolonged period of atrophy in naval ship design and industrial ship building
- Complex nature of rapidly evolving and unpredictable global threat environment
- Proliferation of missions within spectrum of modern conflicts including military operations other than war
- Volatile fiscal and financial environment rendering budgetary forecasting unpredictable



<http://shipsstarthere.ca/cont/1.jpeg>



<http://www.thetimes.co.uk/to/multimedia/archive/00510/8b485da8-83a4-11e3-510078b.jpg>



<http://cimsec.org/wp-content/uploads/2013/10/West-African-Militants.gif>

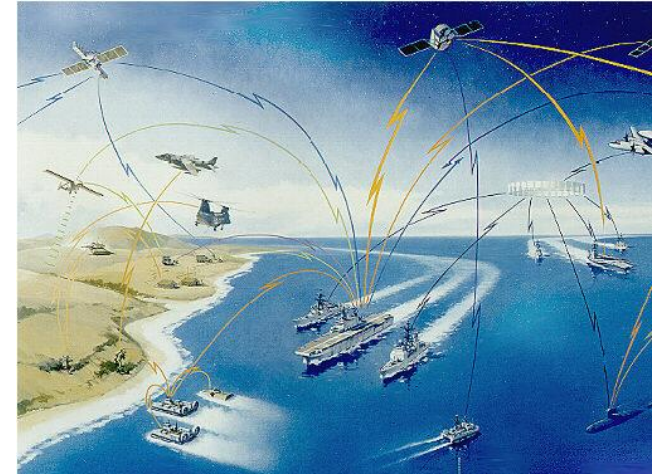


<http://shtplan.com/wp-content/uploads/2013/12/market-crash.jpg>

# Purpose

## Postulation

Modern naval ship design should consider the systems of interest as components subsumed by a holistic environment encompassing assets and capabilities inorganic to naval platforms



<http://www.spawar.navy.mil/sti/publications/pubs/td/2902/td2902.html>

## Motivation

Propose a starting point intended to provide a more defined means of establishing and improving the early phases of the ship design process as part of a multi-layered maritime domain warfare enterprise



<http://tomtunguz.com/images/gears.jpg>

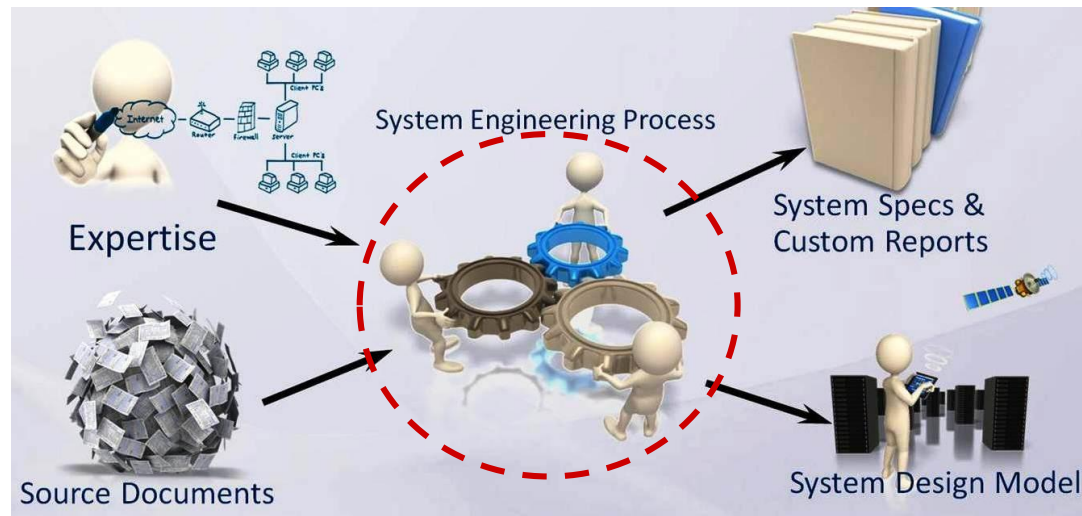
# Model-Based System Engineering

## Methodology

Formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle

## Restraint and Constraint

- Will not eliminate all uncertainties and cover all options related to ship conceptual design
- Will better circumscribe uncertainties so to distill a deeper appreciation of the critical factors



[http://www.incose.org/chesapek/images/Newsletter/2011\\_09\\_17\\_MBSE\\_Diagram.jpg](http://www.incose.org/chesapek/images/Newsletter/2011_09_17_MBSE_Diagram.jpg)



# Benefits

## Cohesion

- Providing a more **structured and cohesive approach** to identifying and assessing ship capability portfolio
- Creating a **common language** and conceptual framework for the way to manage and improve capability-based planning within a ship design process

## Efficiency

- Identifying **capability strengths** and interests to be maintained, developed and exploited
- Identifying **capability deficiencies** (shortcomings or surpluses) to be remedied or accepted
- Ranking ship variants based on operational **effectiveness, capability and affordability trade-offs** across a spectrum of missions' priorities

## Visualisation

- Facilitating comparisons, identifying and allowing the **sharing of best practice** across major ship acquisition projects within an organisation or a **community of practice**
- Assessing and **presenting** the findings from a variety of reviews in a format that is easy to understand

## Engagement

- Involving more **relevant stakeholders** at all levels in the capability-based ship design process
- Educating stakeholders on the fundamental elements of capability-based ship design and how they relate to their **roles and responsibilities**

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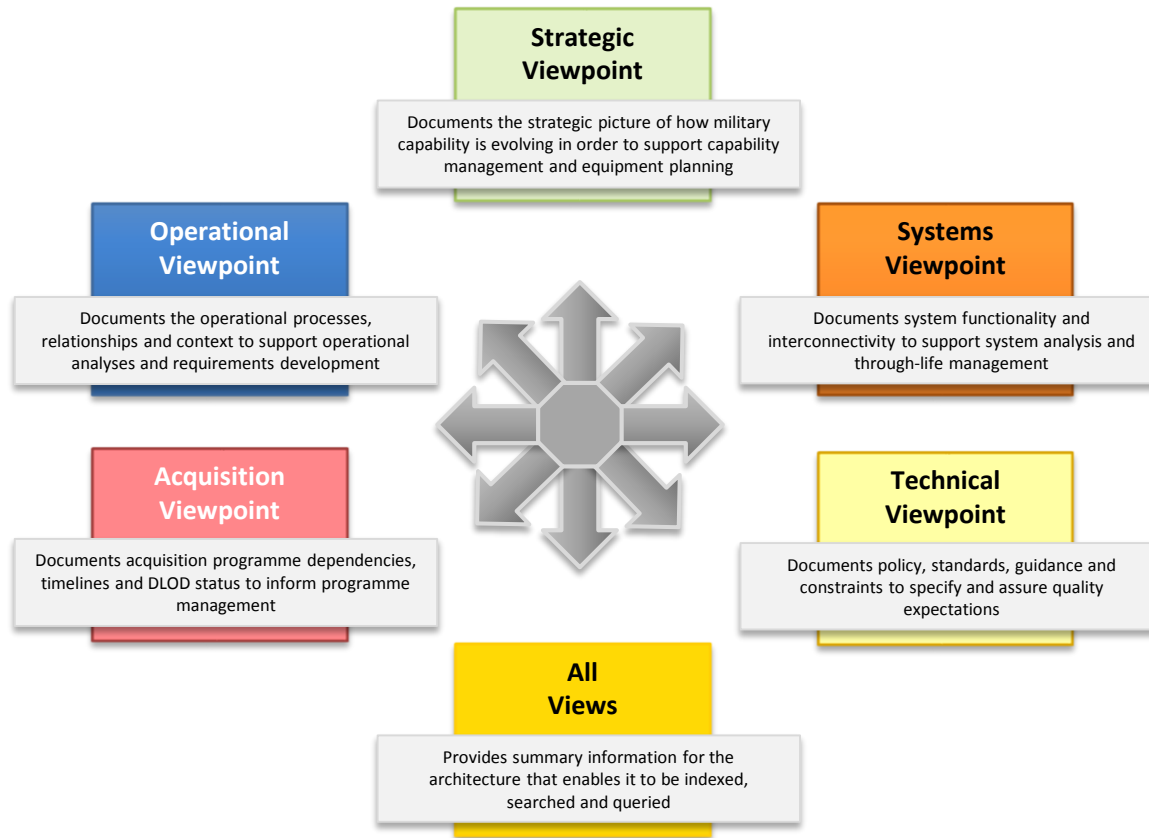
## Engagement

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Proof of Concept



# Enterprise Architectural Framework






## MODAF Viewpoints (2005)

<http://www.modaf.com/files/MODAF%20Acquisition%20Deskbook%20v1.0.pdf>

- Provide “single source of truth” by creating a logical structure for classifying, organising and presenting complex information in a uniform manner
- Improved clarity on the context within which capabilities are introduced and will operate
- Clearer and more comprehensive requirements documents
- Improved ability to resolve interoperability issues between systems
- Better understanding of the mapping of system functions to operational needs and hence the ability to conduct improved trade-offs

# Naval Platforms as SoS

Characteristics	Description	Navy
<b>Operational Independence of the Individual Systems</b>	A system of systems is composed of systems that are independent and useful in their own right. If a system of systems is disassembled into the component systems, these component systems are capable of independently performing useful operations independently of one another.	
<b>Managerial Independence of the Systems</b>	The component systems not only can operate independently, they generally do operate independently to achieve an intended purpose. The component systems are generally individually acquired and integrated and they maintain a continuing operational existence that is independent of the system of systems.	
<b>Geographic Distribution</b>	Geographic dispersion of component systems is often large. Often, these systems can readily exchange only information and knowledge with one another, and not substantial quantities of physical mass or energy.	
<b>Emergent Behaviour</b>	The system of systems performs functions and carries out purposes that do not reside in any component system. These behaviours are emergent properties of the entire system of systems and not the behaviour of any component system. The principal purposes supporting engineering of these systems are fulfilled by these emergent behaviours.	
<b>Evolutionary Development</b>	A system of systems is never fully formed or complete. Development of these systems is evolutionary over time and with structure, function and purpose added, removed, and modified as experience with the system grows and evolves over time.	

[http://4.bp.blogspot.com/\\_eJxGTH9qfo/TzLyEBK2JIAAAAAAAAAAAQk/NGcdh0cWC4st600/carrier-battle-group.jpg](http://4.bp.blogspot.com/_eJxGTH9qfo/TzLyEBK2JIAAAAAAAAAAAQk/NGcdh0cWC4st600/carrier-battle-group.jpg)

[http://defense-update.com/images/large3/dap\\_ground\\_station.jpg](http://defense-update.com/images/large3/dap_ground_station.jpg)

<http://navy-matters.beedall.com/images/brightnetcentric.jpg>

# Capacity + Ability = Capability

## Capacity

- Quantitative
- Resources
- “What”
- “Means”

## Ability

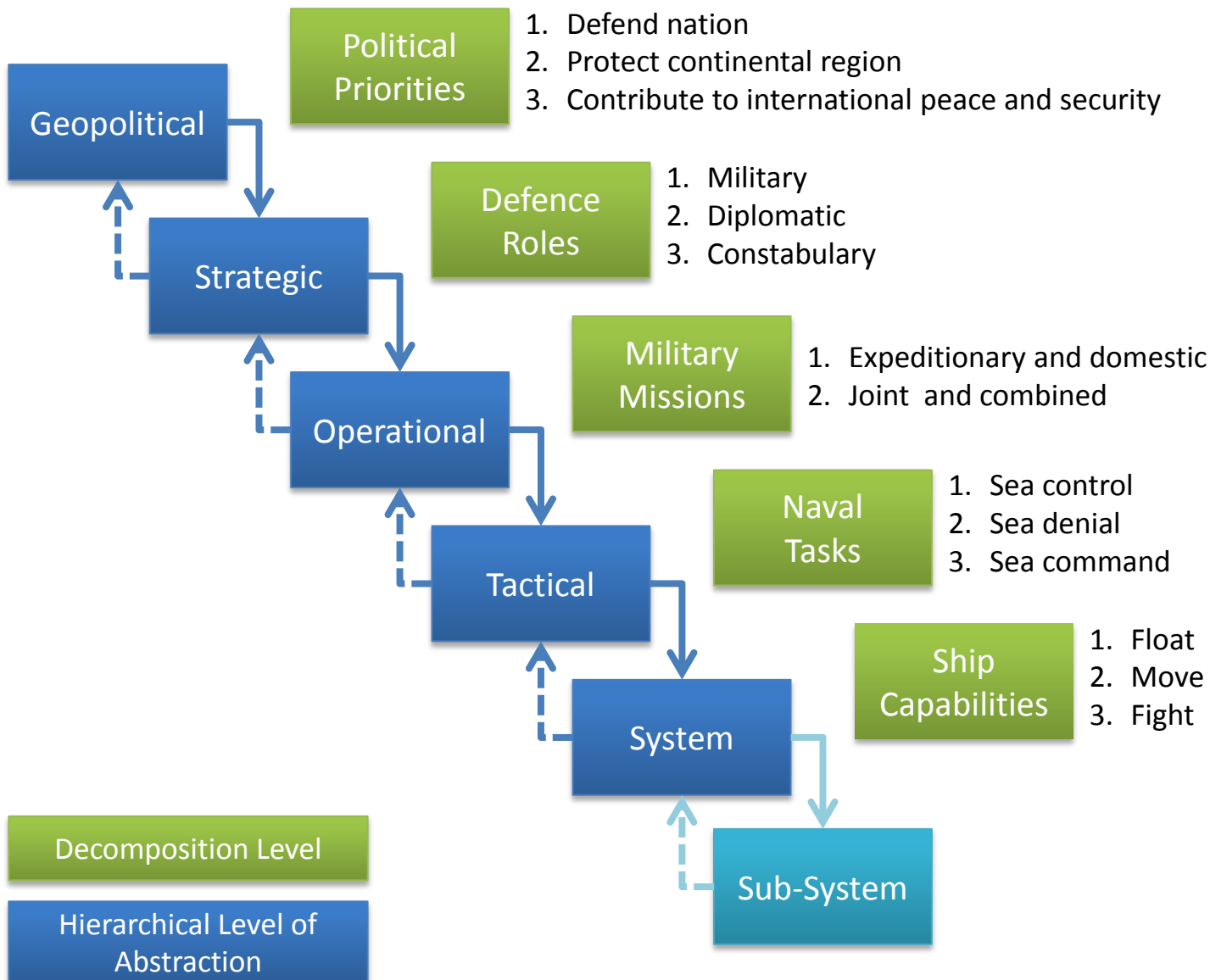
- Qualitative
- Methods
- “How”
- “Ways”

- The “means” describe “what” resources are adequate to achieve these objectives within an acceptable level of risk
- The “ways” are the strategic and operational methods describing “how” to conduct military operations to accomplish the specific military objectives, the “ends”

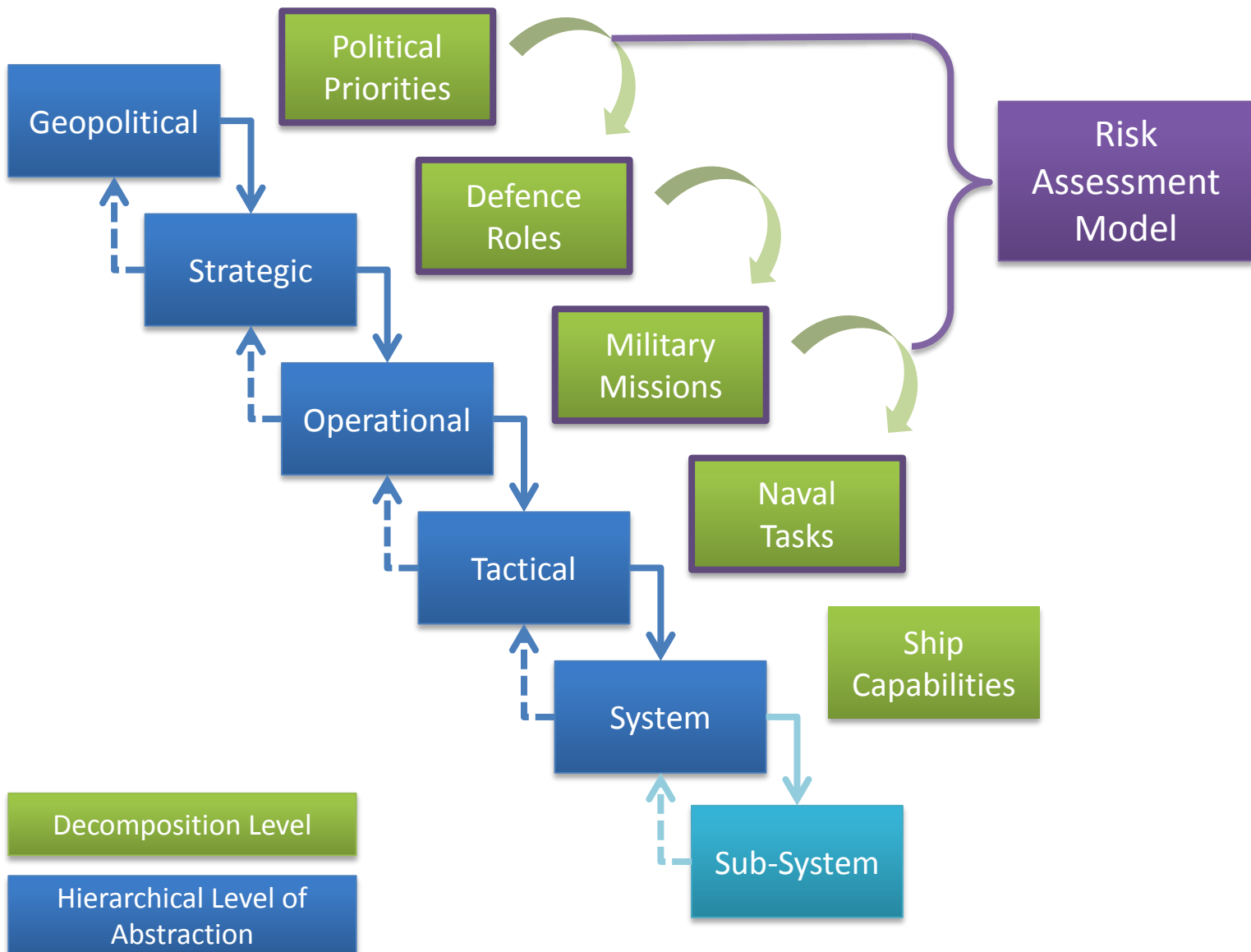


[http://patdollar.com/wp-content/uploads/2012/09/us\\_armada\\_iraq.jpg](http://patdollar.com/wp-content/uploads/2012/09/us_armada_iraq.jpg)

# Hierarchical Decomposition

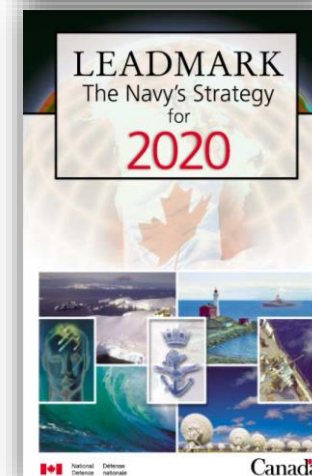
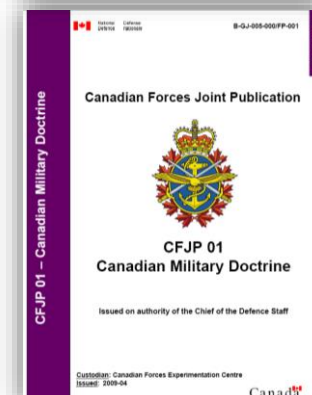


# Hierarchical Decomposition



Frequency	Impact						Geo-political	Strategic	Operational						
	Critical	Major	Moderate	Minor	Insignificant	Not Applicable	Roles	Defence Policy Priorities	Domestic Tasks	Expeditionary Tasks					
							1. Defend Canada	2. Defend North America	3. Contribute to International Peace and Security	1. Conduct daily domestic and continental operations	2. Support a major international event in Canada	3. Support civilian authorities during a crisis in Canada such as a natural disaster	4. Respond to a major terrorist attack	5. Lead and/or conduct a major international operation for an extended period	6. Deploy forces in response to crises elsewhere in the world for shorter periods
Always	VH	VH	H	M	L	NA									
Likely	VH	H	M	L	VL	NA									
Possibly	H	M	M	L	VL	NA									
Unlikely	M	L	L	L	VL	NA									
Rarely	L	VL	VL	VL	VL	NA									
Never	NA	NA	NA	NA	NA	NA									

Strategic	Defence Policy Priorities	Operational						Tactical	Naval Functions						
		Domestic Tasks		Expeditionary Tasks											
Strategic	1. Conduct daily domestic and continental operations	VH	VH	VL	VL	VL	VL	Tactical	1. Air and Maritime Search and Rescue (SAR)						
	2. Support a major international event in Canada	H	M	VL	VL	VL	VL		2. Humanitarian Assistance						
	3. Support civilian authorities during a crisis in Canada such as a natural disaster	M	VL	NA	VL	VL	VL		3. Assistance to Law Enforcement Agencies (ALEA)						
	4. Respond to a major terrorist attack	VL	VL	VL	VL	VL	VL		4. Fisheries Patrols						
	5. Lead and/or conduct a major international operation for an extended period	VL	L	VH	VL	VL	VL		5. Sovereignty Patrols						
	6. Deploy forces in response to crises elsewhere in the world for shorter periods	VL	L	VH	VL	VL	VL		6. Arctic Sovereignty Patrols						
Operational	Domestic Tasks	1. Air and Maritime Search and Rescue (SAR)	H	M	H	VL	VL	VL	Tactical	7. Maritime Interdiction Operations (MIO)					
		2. Humanitarian Assistance	M	M	H	M	L	M		8. Non-combatant Evacuation Operations (NEO)					
		3. Assistance to Law Enforcement Agencies (ALEA)	L	VH	VH	VH	VH	L		9. Littoral Maritime Force Projection					
		4. Aid to Civil Power	VL	VL	VL	H	M	M		10. Standing NATO Response Force Maritime Group 1 (SNMG1)					
		5. Sovereignty Operations	VH	H	M	VH	M	M		11. United States Task Group (e.g., CSG, ESG, MEU)					
		6. International Humanitarian Relief Operations (HUMRO)	L	L	L	L	M	H							
	Expeditionary Tasks	7. Non-combatant Evacuation Operations (NEO)	VL	NA	NA	VH	VH	L							
		8. Counter-Insurgency Operations (COINOPs)	VL	VL	VL	VH	VL	VL							
		9. CANUS Continental Operations	VH	VH	VL	VL	VL	VL							
		10. Stabilization Operations	VL	VL	VL	M	VH	VL							
		11. NATO Response Force (NRF) Operations	VL	VL	VL	L	VH	VH							
		12. Peace Support Operations (PSO) - UN Chapter VI	VL	VL	VL	L	VH	VH							
		13. Peace Enforcement - UN Chapter VII	VL	VL	VL	VH	VH	VH							
		14. Major Combat Operations (MCO)	VL	VL	VL	VH	H	H							
Tactical	Naval Functions	1. Air and Maritime Search and Rescue (SAR)	VH	VH	H	VL	L	VH	VH	H	M	M	VL	VL	VL
		2. Humanitarian Assistance	M	H	M	VL	M	H	H	VL	L	M	M	VL	VL
		3. Assistance to Law Enforcement Agency	VH	VH	VH	VH	L	VL	L	VL	L	H	H	VH	VL
		4. Fisheries Patrols	NA	NA	VH	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		5. Sovereignty Patrols	VH	H	H	VL	VH	VL	M	H	VH	H	H	VL	VL
		6. Arctic Sovereignty Patrols	VL	VL	VL	VL	VL	VL	VL	M	VL	VL	H	H	M
		7. Maritime Interdiction Operations (MIO)	NA	NA	M	VH	L	M	H	M	VH	VH	VH	VH	VH
		8. Non-combatant Evacuation Operations (NEO)	NA	NA	NA	NA	NA	M	VH	H	VL	H	H	H	M
		9. Littoral Maritime Force Projection	NA	NA	VL	VL	L	M	M	H	L	VH	VH	VH	VH
		10. Standing NATO Response Force Maritime Group 1 (SNMG1)	NA	VL	VL	VL	M	VL	VL	H	H	VH	H	H	VH
		11. United States Task Group (e.g., CSG, ESG, MEU)	NA	VL	VL	M	VL	VL	VL	H	H	M	M	M	VH



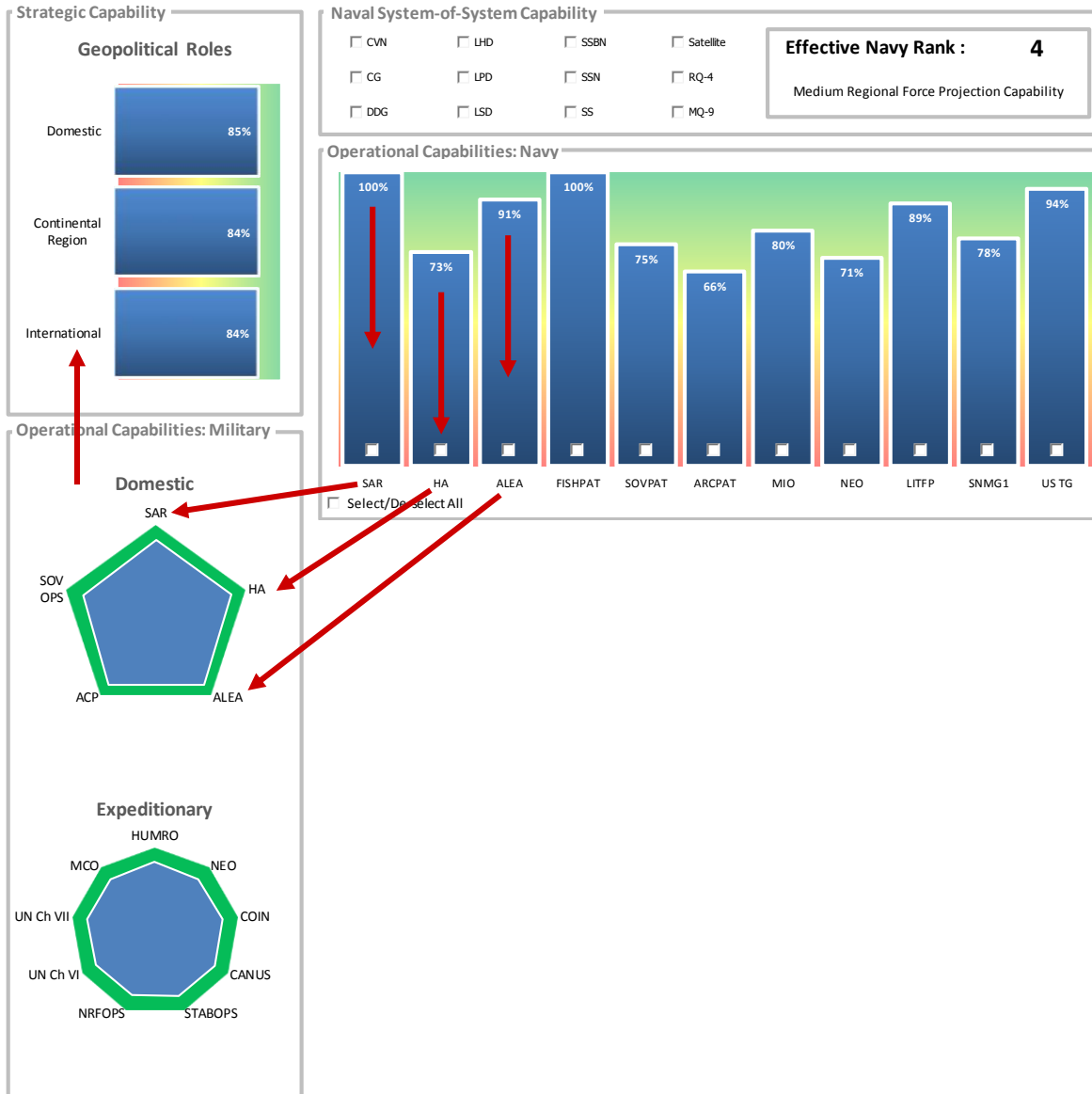


# Naval SoS Levels

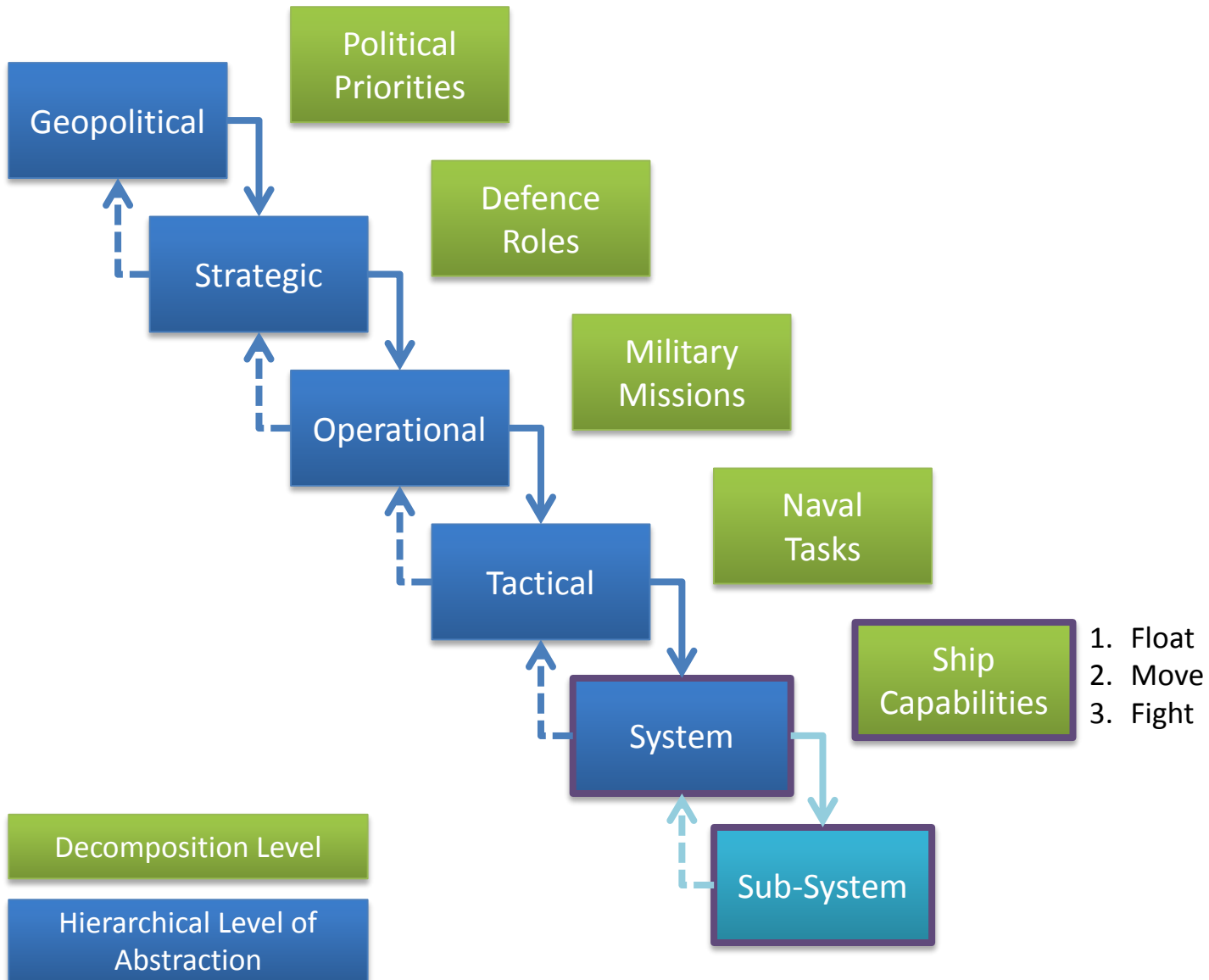
Rank	Typology	Description
<b>1</b>	<b>Complete Major Global Force Projection</b>	Capable of carrying out all the military roles of naval forces on a global scale. It possesses the full range of carrier and amphibious capabilities, sea control forces, and nuclear attack and ballistic missile submarines, and all in sufficient numbers to undertake major operations independently.
<b>2</b>	<b>Partial Global Force Projection</b>	Possesses most if not all of the force projection capabilities of a "complete" global navy, but only in sufficient numbers to undertake one major "out of area" operation.
<b>3</b>	<b>Medium Global Force Projection</b>	May not possess the full range of capabilities, but have a credible capacity in certain of them and consistently demonstrate a determination to exercise them at some distance from home waters, in cooperation with other Force Projection Navies.
<b>4</b>	<b>Medium Regional Force Projection</b>	Possesses the ability to project force into the adjoining ocean basin. While may have the capacity to exercise these further afield, for whatever reason, do not do so on a regular basis.
<b>5</b>	<b>Adjacent Force Projection</b>	Possesses some ability to project force well offshore, but not capable of carrying out high-level naval operations over oceanic distances.
<b>6</b>	<b>Offshore Territorial Defence</b>	Possesses relatively high levels of capability in defensive (and constabulary) operations up to about 200 miles from shores, having the sustainability offered by frigate or large corvette vessels and (or) a capable submarine force.
<b>7</b>	<b>Inshore Territorial Defence</b>	Primarily inshore territorial defence capabilities, capable of coastal combat rather than constabulary duties alone. This implies a force comprising missile-armed fast-attack craft, short-range aviation and a limited submarine force.
<b>8</b>	<b>Constabulary Defence</b>	Not intended to fight, but to act purely in a constabulary role.



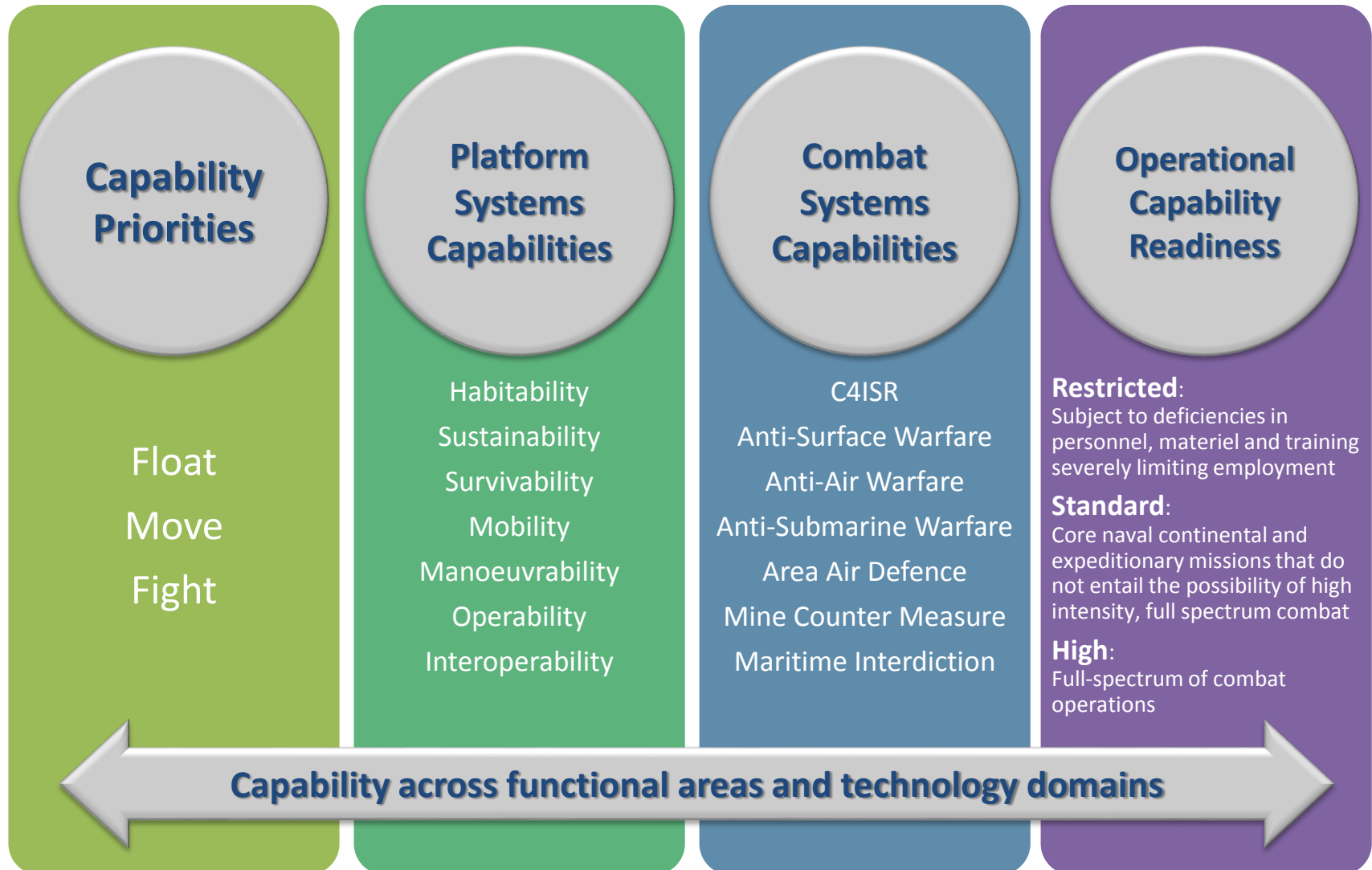
# Visualization 1



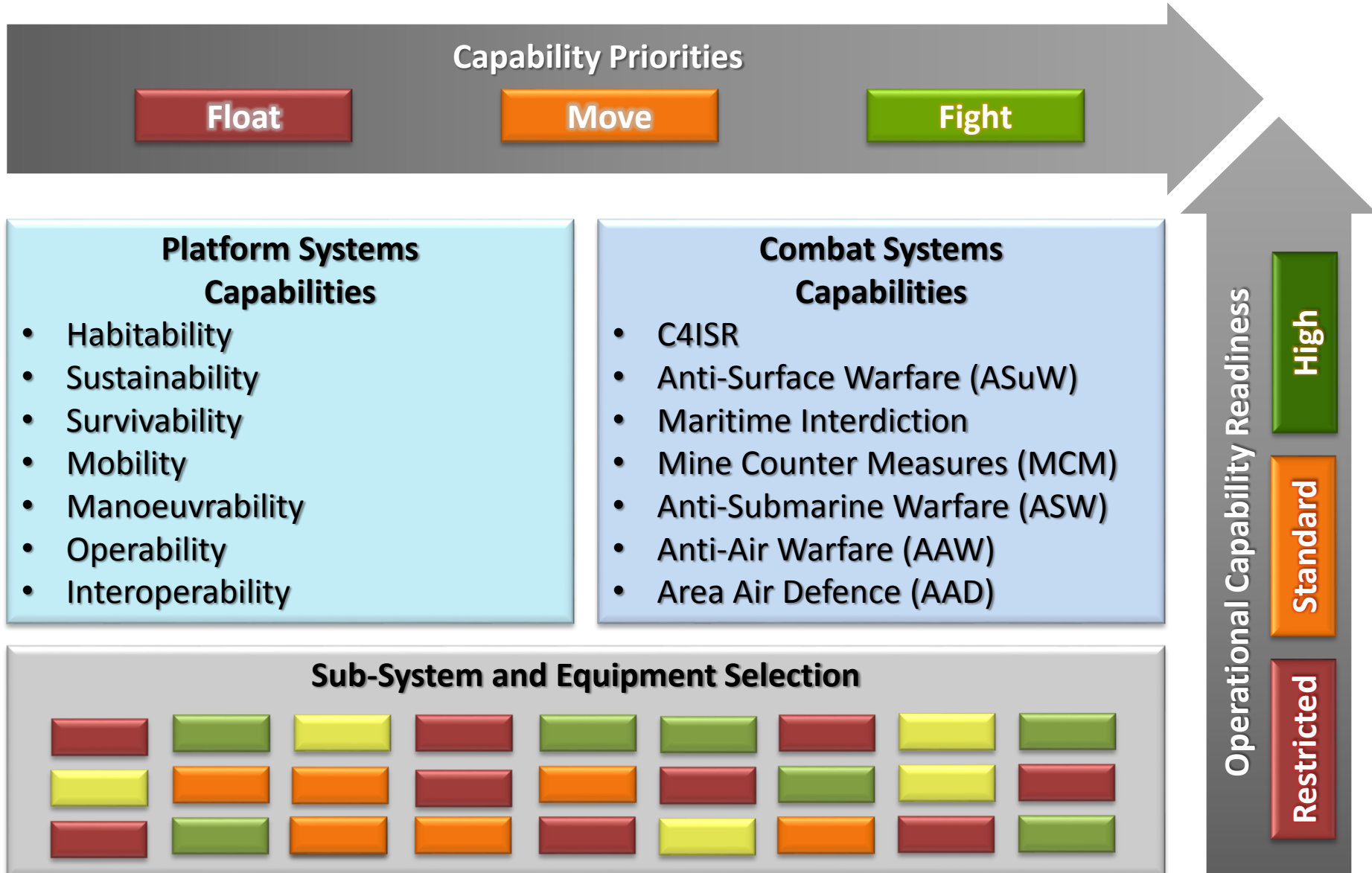
# Hierarchical to Functional Decomposition



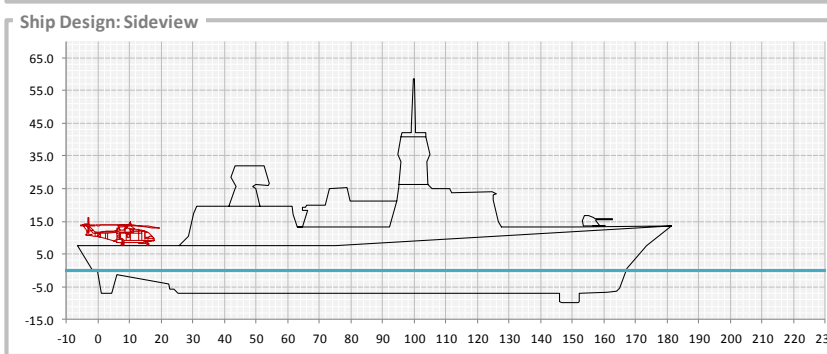
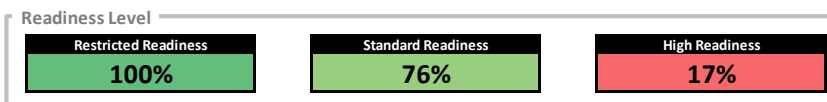
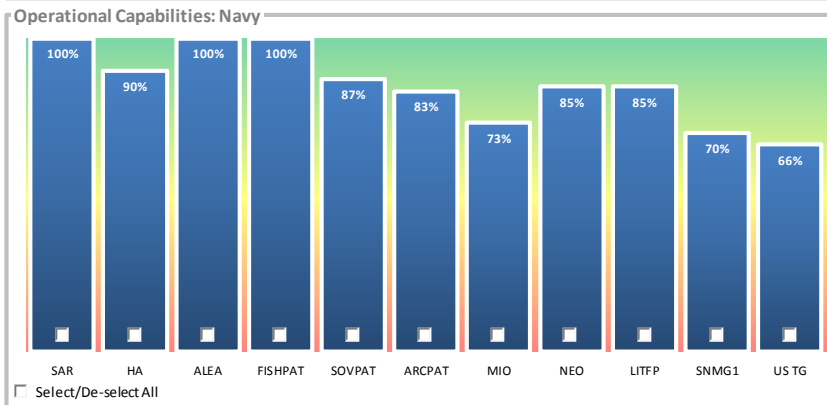
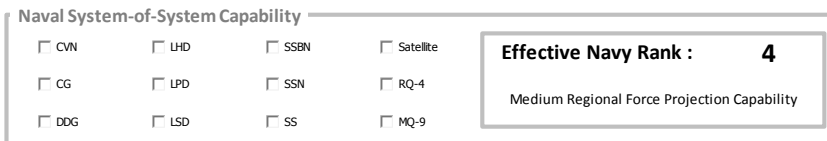
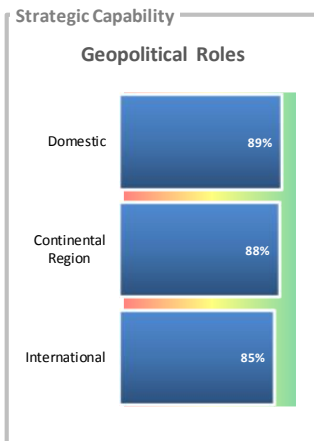
# Cross-Functional Decomposition



# Cross-Functional Decomposition

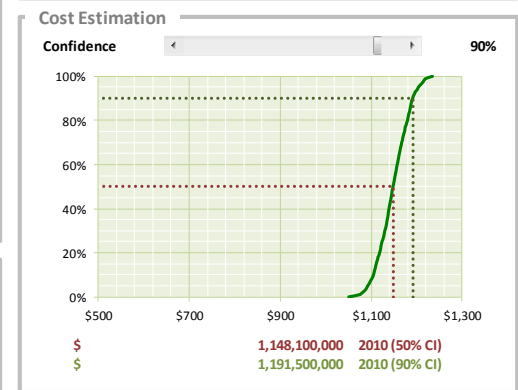
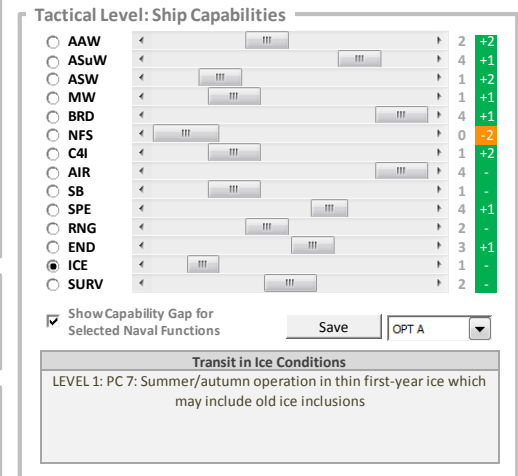
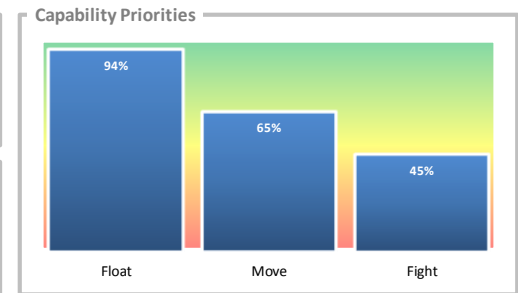


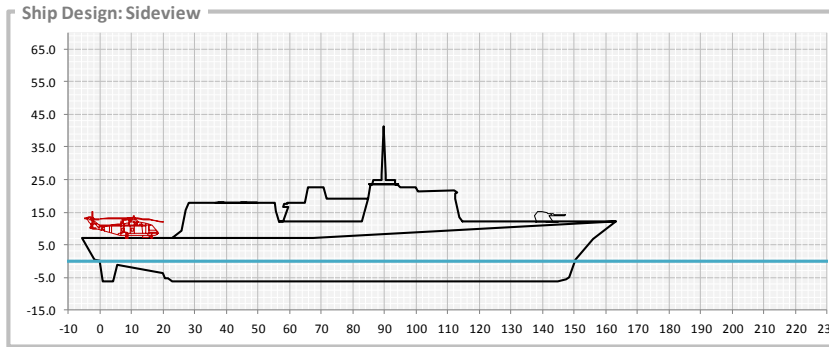
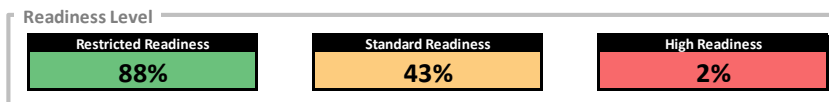
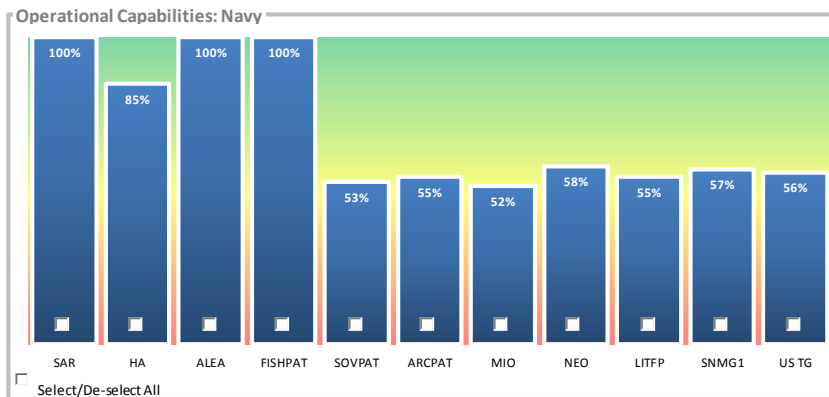
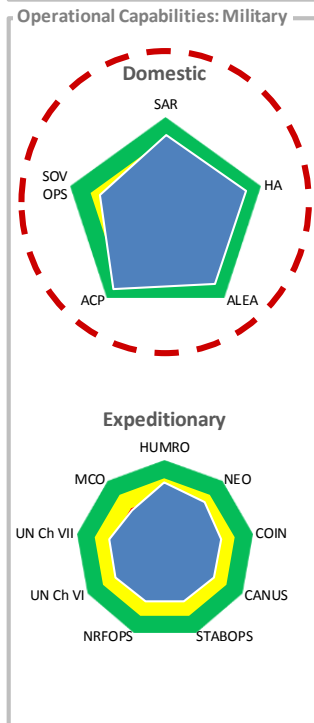
# Visualization 2



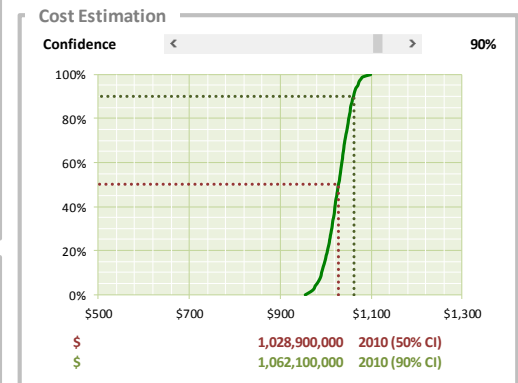
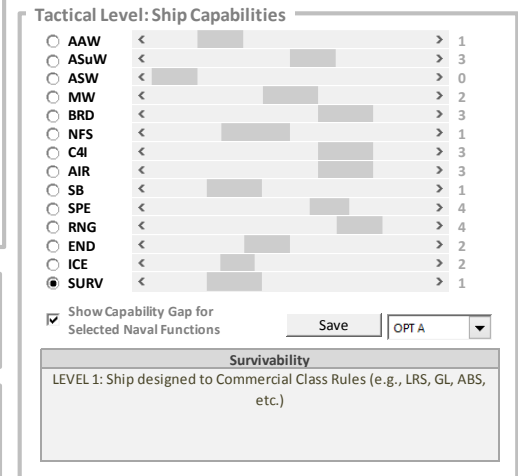
### Ship Design: Key Parameters

Characteristics	Limit	Value	Characteristics	Limit	Value
Displacement (Δ)	8,500	10,601	Complement	200	200 sailors
Length Overall (LOA)	165.0	187.8 m	In-Hull Volume	7,500	5,200 m³
Beam (B)	16.0	16.1 m	Air Draught	35.0	58.6 m
Draught (T)	7.0	7.0 m	Flightdeck Length	30.0	30.0 m





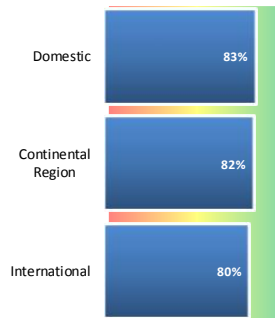
Ship Design: Key Parameters					
Characteristics		Limit	Value	Characteristics	
Displacement (Δ)		8,500	7,711	Complement	200
Length Overall (LOA)		165.0	168.9	In-Hull Volume	7,500
Beam (B)		16.0	14.5	Air Draught	35.0
Draught (T)		7.0	6.3	Flightdeck Length	30.0



# Expeditionary Variant

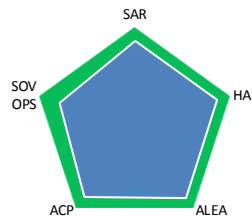
## Strategic Capability

### Geopolitical Roles

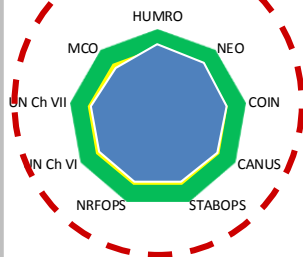


## Operational Capabilities: Military

### Domestic



### Expeditionary



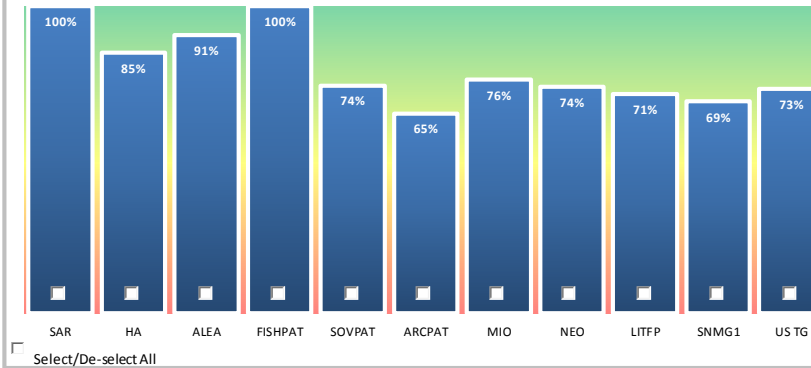
## Naval System-of-System Capability

- ☐ CVN ☐ LHD ☐ SSBN ☐ Satellite  
☐ CG ☐ LPD ☐ SSN ☐ RQ-4  
☐ DDG ☐ LSD ☐ SS ☐ MQ-9

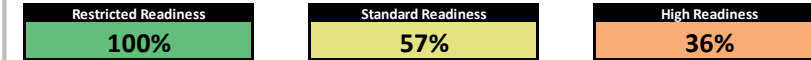
Effective Navy Rank : 5

Adjacent Force Projection Capability

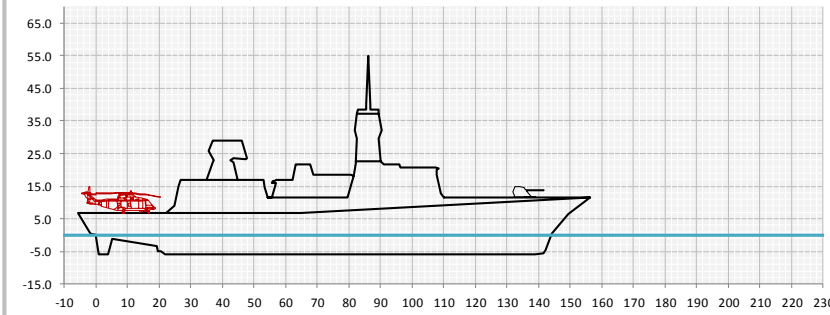
## Operational Capabilities: Navy



## Readiness Level



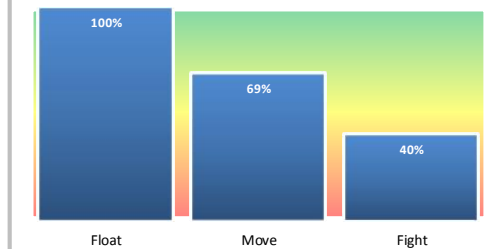
## Ship Design: Sideview



## Ship Design: Key Parameters

Characteristics	Limit	Value		Characteristics	Limit	Value	
Displacement (Δ)	8,500	6,794	LT	Complement	200	176	sailors
Length Overall (LOA)	165.0	162.0	m	In-Hull Volume	7,500	4,200	m <sup>3</sup>
Beam (B)	16.0	13.9	m	Air Draught	35.0	55.0	m
Draught (T)	7.0	6.0	m	Flightdeck Length	30.0	25.6	m

## Capability Priorities



## Tactical Level: Ship Capabilities



Show Capability Gap for Selected Naval Functions

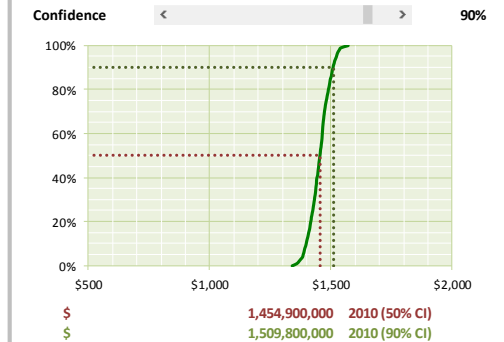
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OPT A

### Range

LEVEL 3: Ship has a maximum range at cruise speed between 5,000 nmi and 7,500 nmi

## Cost Estimation

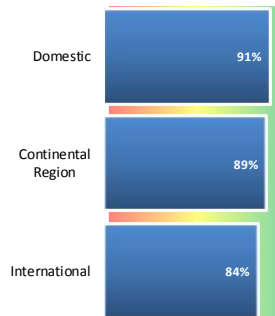




# Arctic Patrol Variant

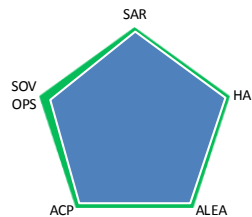
## Strategic Capability

### Geopolitical Roles

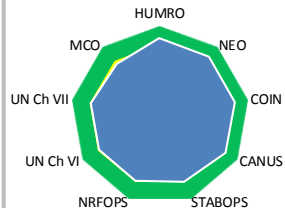


## Operational Capabilities: Military

### Domestic



### Expeditionary



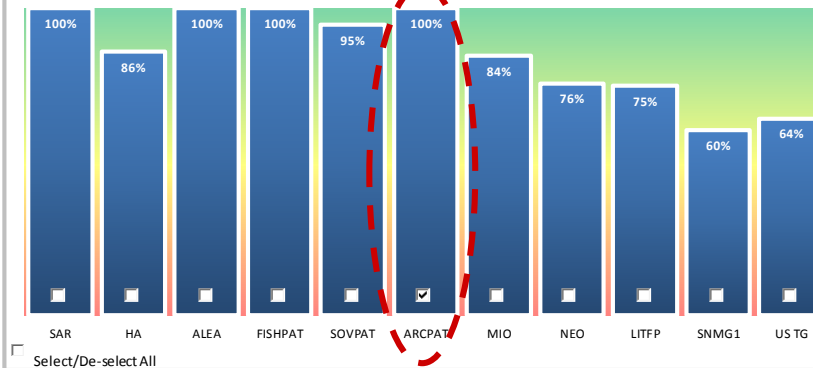
## Naval System-of-System Capability

- ☐ CVN ☐ LHD ☐ SSBN ☐ Satellite
- ☐ CG ☐ LPD ☐ SSN ☐ RQ-4
- ☐ DDG ☐ LSD ☐ SS ☐ MQ-9

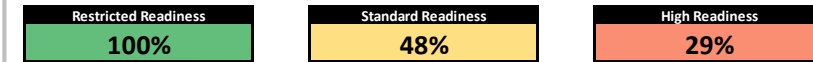
Effective Navy Rank : 5

Adjacent Force Projection Capability

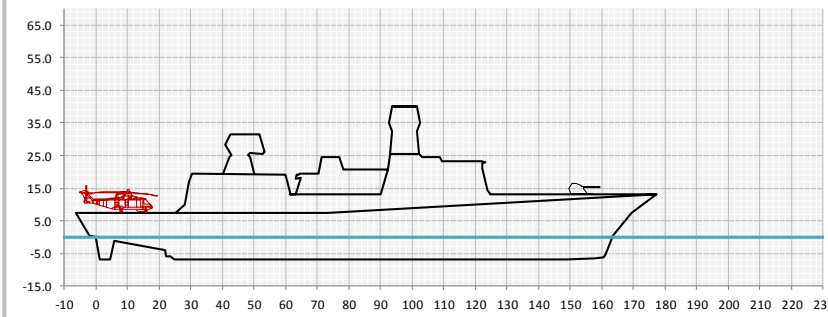
## Operational Capabilities: Navy



## Readiness Level



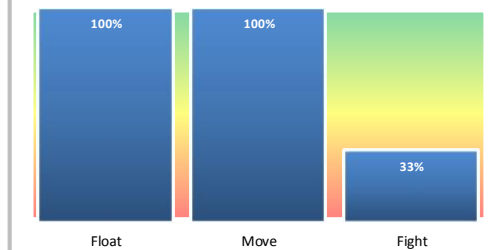
## Ship Design: Sideview



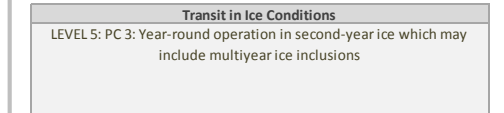
## Ship Design: Key Parameters

Characteristics	Limit	Value		Characteristics	Limit	Value	
Displacement (Δ)	8,500	9,908	LT	Complement	200	186	sailors
Length Overall (LOA)	165.0	183.7	m	In-Hull Volume	7,500	4,000	m³
Beam (B)	16.0	15.7	m	Air Draught	35.0	40.2	m
Draught (T)	7.0	6.8	m	Flightdeck Length	30.0	29.3	m

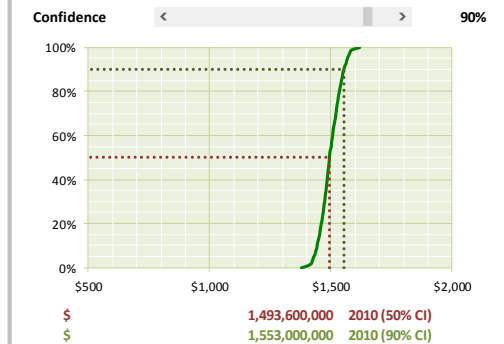
## Capability Priorities



## Tactical Level: Ship Capabilities



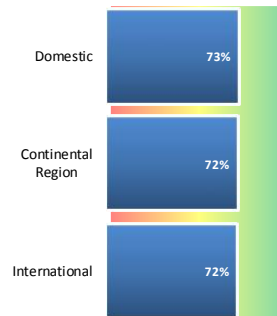
## Cost Estimation



# Non-Combatant Evacuation (NEO) Variant

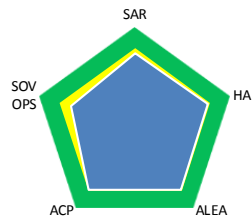
## Strategic Capability

### Geopolitical Roles

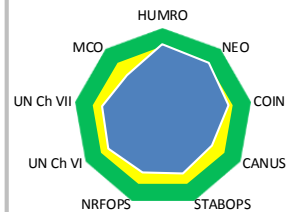


## Operational Capabilities: Military

### Domestic



### Expeditionary



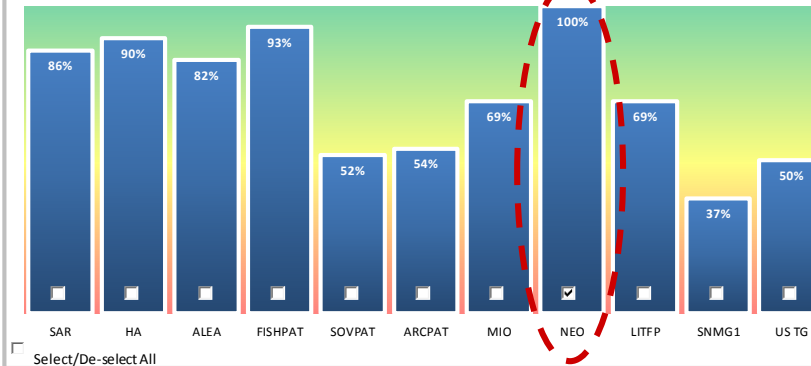
## Naval System-of-System Capability

- ☐ CVN ☐ LHD ☐ SSBN ☐ Satellite
- ☐ CG ☐ LPD ☐ SSN ☐ RQ-4
- ☐ DDG ☐ LSD ☐ SS ☐ MQ-9

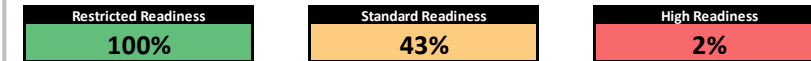
Effective Navy Rank : 6

Offshore Territorial Defence Capability

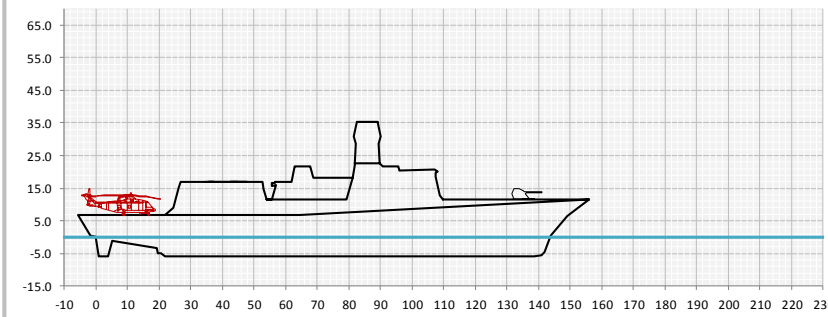
## Operational Capabilities: Navy



## Readiness Level



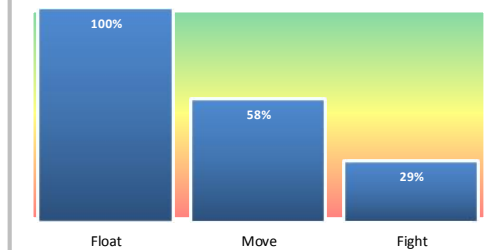
## Ship Design: Sideview



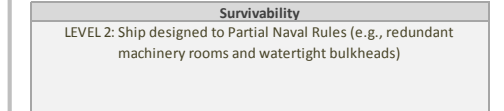
## Ship Design: Key Parameters

Characteristics	Limit	Value		Characteristics	Limit	Value	
Displacement (Δ)	8,500	6,730	LT	Complement	200	177	sailors
Length Overall (LOA)	165.0	161.4	m	In-Hull Volume	7,500	4,000	m <sup>3</sup>
Beam (B)	16.0	13.8	m	Air Draught	35.0	35.3	m
Draught (T)	7.0	6.0	m	Flightdeck Length	30.0	25.5	m

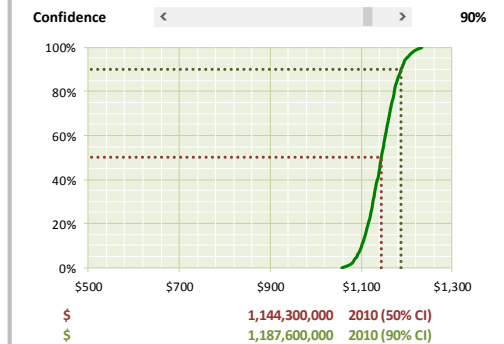
## Capability Priorities



## Tactical Level: Ship Capabilities



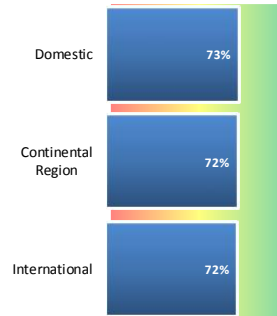
## Cost Estimation



# (Imbalanced) Maritime Interdiction Ops Variant

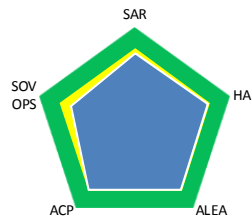
## Strategic Capability

### Geopolitical Roles

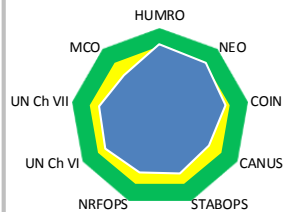


## Operational Capabilities: Military

### Domestic



### Expeditionary



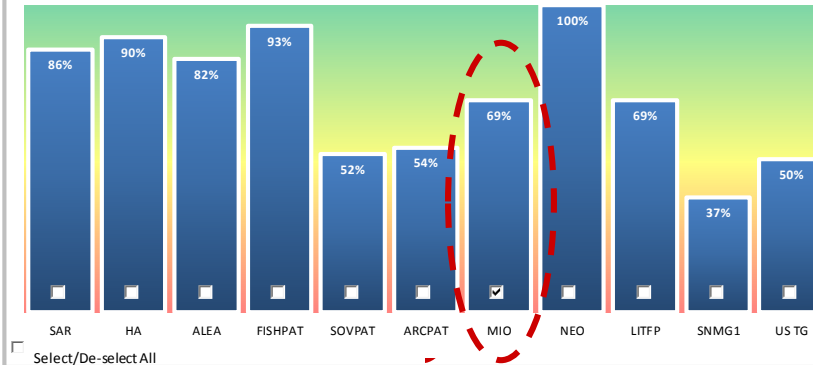
## Naval System-of-System Capability

- ☐ CVN
- ☐ LHD
- ☐ SSBN
- ☐ Satellite
- ☐ CG
- ☐ LPD
- ☐ SSN
- ☐ RQ-4
- ☐ DDG
- ☐ LSD
- ☐ SS
- ☐ MQ-9

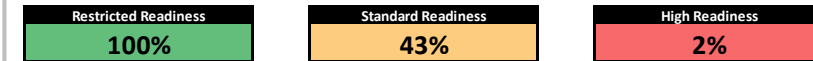
Effective Navy Rank : 6

Offshore Territorial Defence Capability

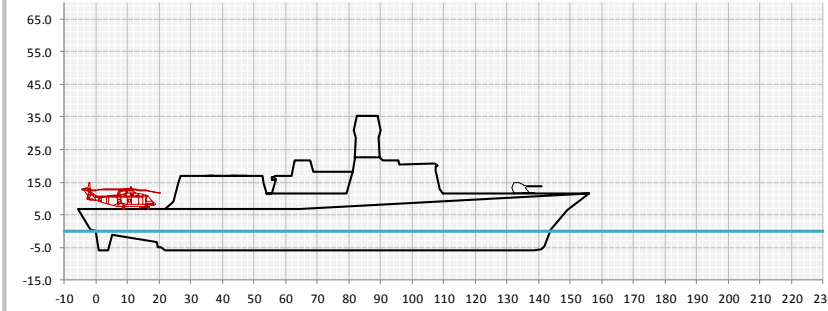
## Operational Capabilities: Navy



## Readiness Level



## Ship Design: Sideview

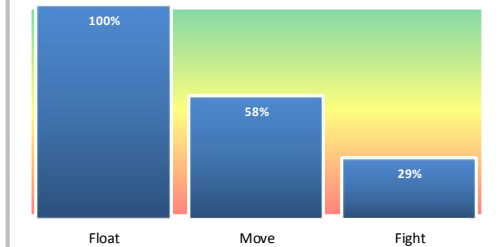


## Ship Design: Key Parameters

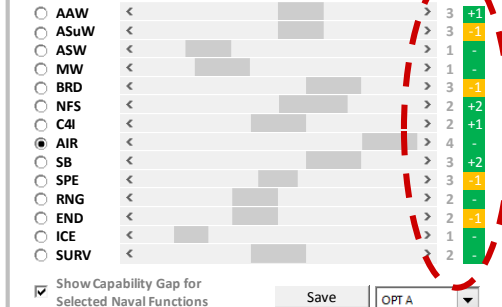
Characteristics	Limit	Value	Unit
Displacement (Δ)	8,500	6,730	LT
Length Overall (LOA)	165.0	161.4	m
Beam (B)	16.0	13.8	m
Draught (T)	7.0	6.0	m

Characteristics	Limit	Value	Unit
Complement	200	177	sailors
In-Hull Volume	7,500	4,000	m³
Air Draught	35.0	35.3	m
Flightdeck Length	30.0	25.5	m

## Capability Priorities

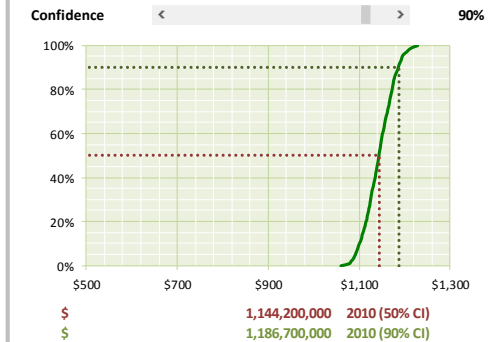


## Tactical Level: Ship Capabilities

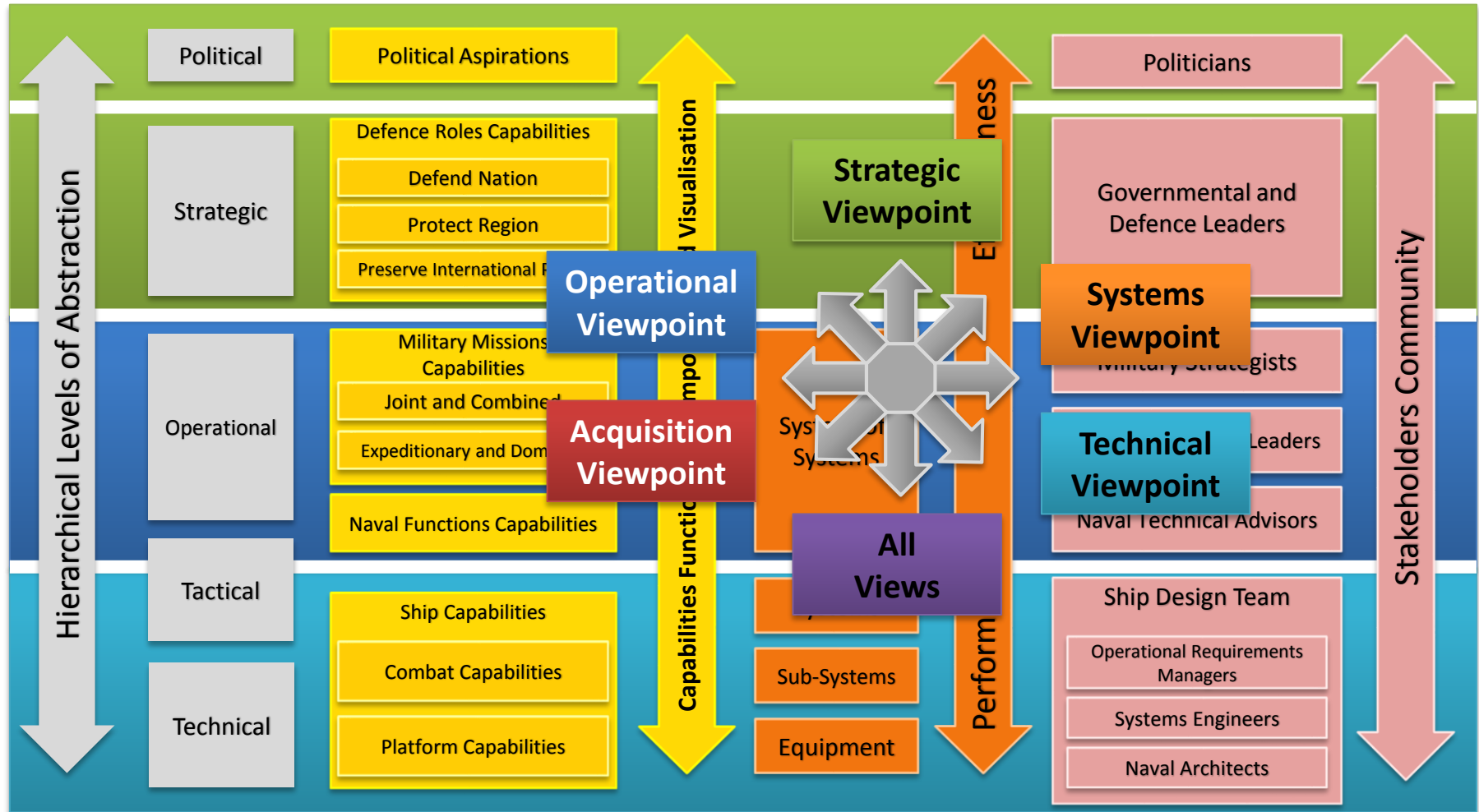


LEVEL 4: Capability to maintain and support multiple air assets onboard (e.g., CH-148 + Firescout)

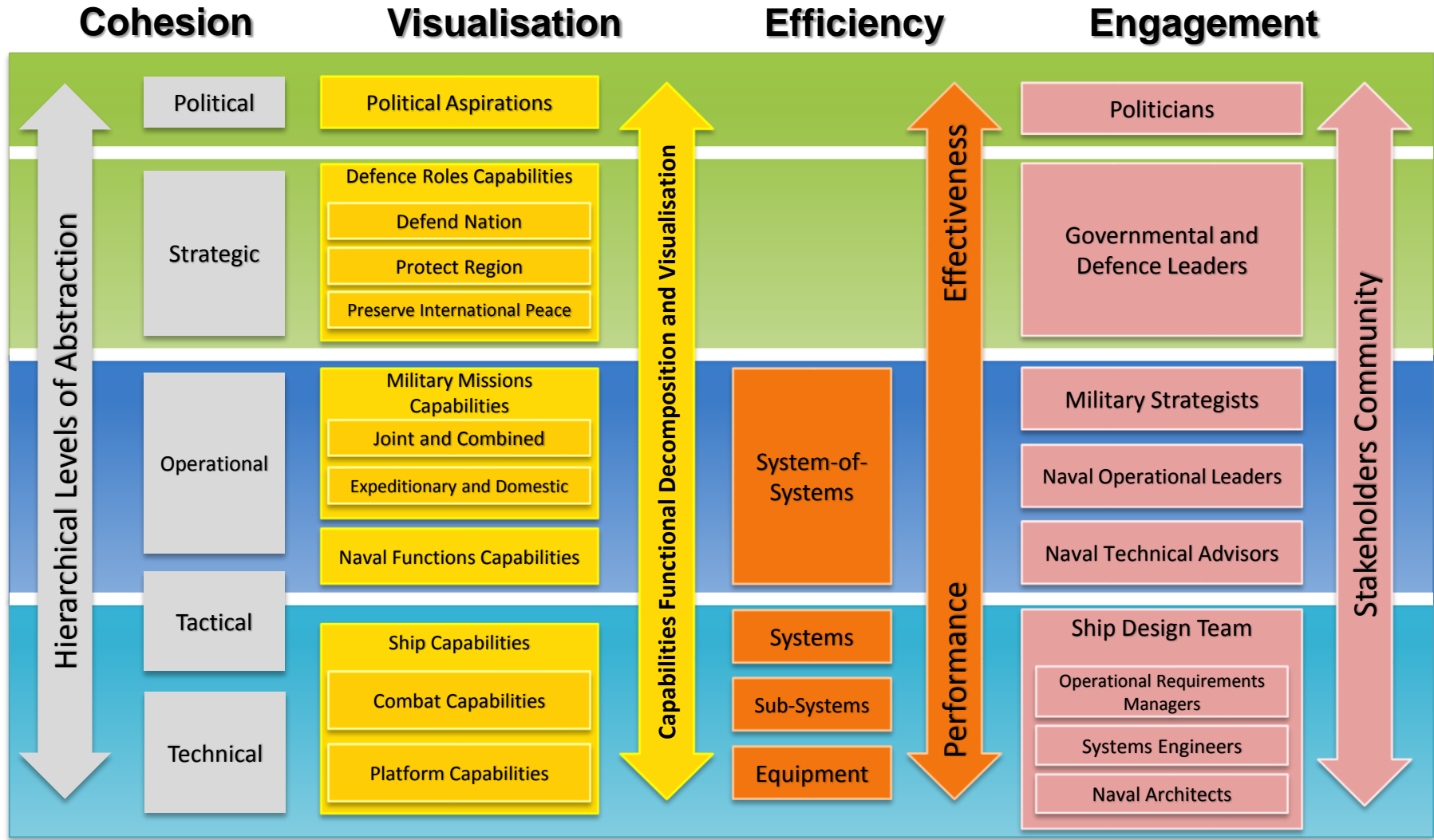
## Cost Estimation



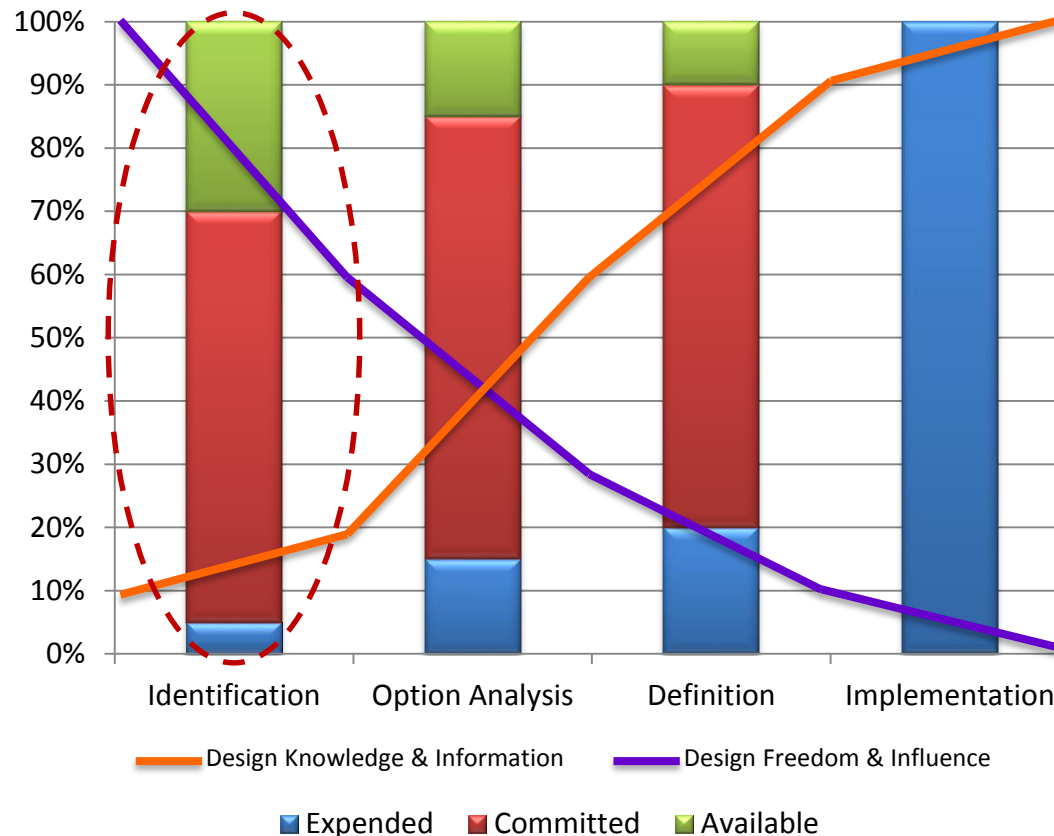
# Capability-based SoS Approach to Naval Ship Design



# Capability-based SoS Approach to Naval Ship Design

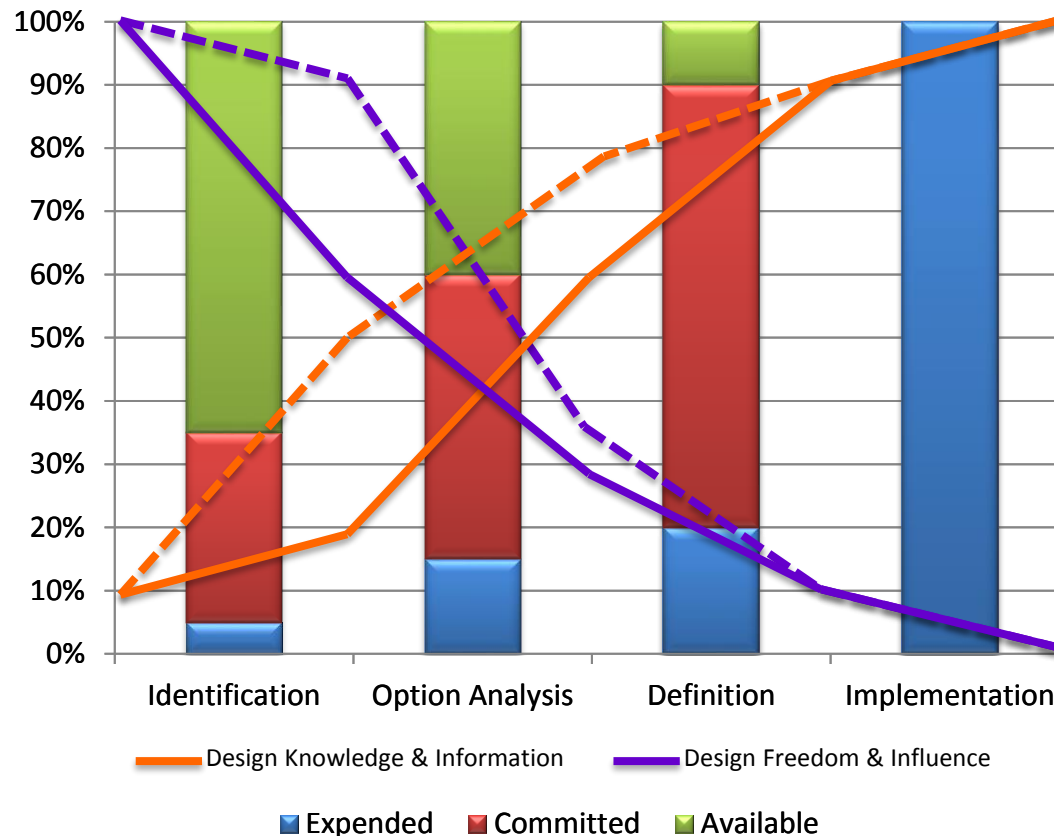


# Design Process Paradox



**Use SoSE methodology and apply MBSE techniques to naval ship design to enable rapid, defensible and traceable capability trade-offs in the early stages of design**

# Design Process Paradox



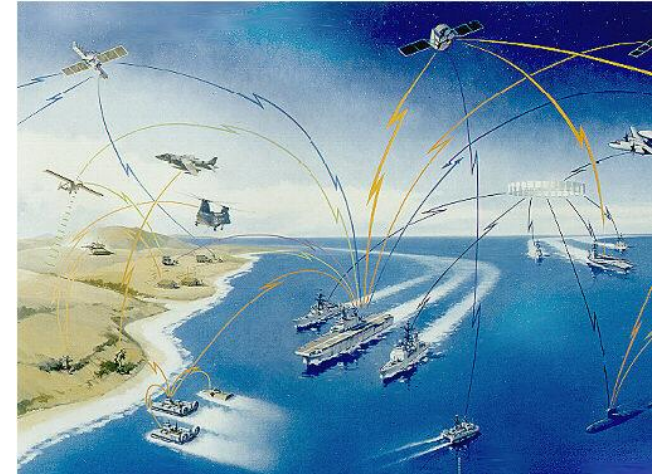
**Use SoSE methodology and apply MBSE techniques to naval ship design to enable rapid, defensible and traceable capability trade-offs in the early stages of design**



# Purpose Revisited

## Postulation

Modern naval ship design should consider the systems of interest as components subsumed by a holistic environment encompassing assets and capabilities inorganic to naval platforms



<http://www.spawar.navy.mil/sti/publications/pubs/td/2902/td2902.html>

## Motivation

Propose a starting point intended to provide a more defined means of establishing and improving the ship design process as part of a multi-layered maritime domain warfare enterprise



<http://tomtunguz.com/images/gears.jpg>

# Questions?

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