Electric Plant Load Analysis

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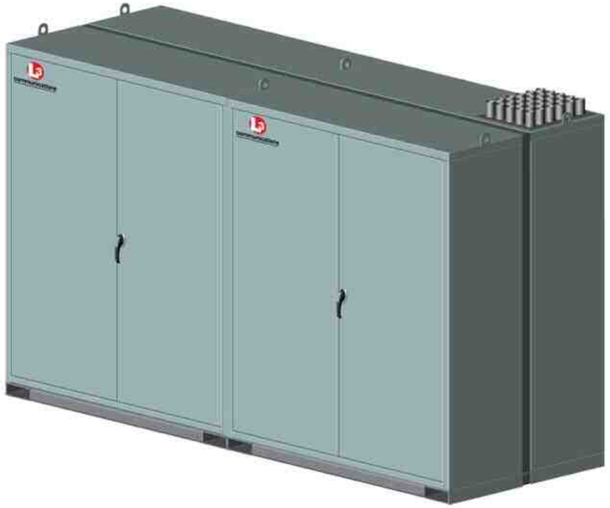
Motivation

- Traditional Electric Power Load Analysis (EPLA) no longer sufficient for Power Electronics based powers distribution systems.
  - Different levels of aggregation
  - Different thermal time constants
  - Different impacts of overloads
- Also need to address new concerns
  - Common mode behavior
  - Impact of controls
  - In-Rush
  - Energy Storage
  - Pulsed Loads

Courtesy L3T

U.S. Navy photo by Mass Communication Specialist 3rd Class Robert S. Price



https://www.l-3mps.com/powerparagon/pdfs/MVMD%202011.pdf

https://www.l-3mps.com/powerparagon/pdfs/Bulletin%20310%20-09.pdf

Viewgraph from “Electric Load Modeling”, Dr. Norbert Doerry and Dr. John Amy Jr, ASNE Intelligent Ships Symposium, Philadelphia PA, April 9-10, 2019.

Design Activities

Design Activities are Building Blocks for Constructing a Design Process

- 100 Develop Power System Architectures
- 200 Electric Power Load Analysis (EPLA)
- 300 Load List
- 400 Primary Power System Design
- 500 Zonal Power System Design
- 600 Propulsion System Design
- 700 Casualty Power System Design
- 800 ES Concept of Operations
- 900 Electric Plant and Propulsion Controls
- 1000 Endurance and Annual Fuel
- 1100 Dynamic Simulation
- 1200 Reliability Analysis
- 1300 Quality of Service Analysis
- 1400 Vulnerability and Recoverability Analysis
- 1500 Arc Flash Analysis
- 1600 System Safety Analysis and Hazard Analysis
- 1700 Cybersecurity Analysis
- 1800 Product Support Analysis
- 1900 Human Engineering Analysis
- 2000 Develop Specifications
- 2100 Develop strategy for power system flexibility
- 2200 Assess Power System flexibility
- 2300 Electrical System and Propulsion System Development Testing
- 2400 Develop mission System - Power System Interface
- 2500 Cost Engineering Analysis
- 2600 Develop Configurations
- 2700 Set Reduction

Requirements

Power System Requirements	R010
Ship Operating Conditions	R020
Margin and Service Life Allowance Policy	R030
Ambient condition Profile	R040
Machinery Arrangements	R050
General Arrangements	R060
Master Equipment List	R070
Combat Systems Design	R080
Other Distributed System Design	R090
Speed Power Curve	R100
Survivability Requirements	R110
QOS Requirements	R120
Endurance Requirements	R130
Operational Profiles	R140
System Safety Plan	R150
Security Controls (from Risk Management Framework)	R160
Product Support Analysis Plan	R170
Flexibility Requirements	R180
Build Plan	R190
Zone Boundaries	R200
SDM Guidance	R210

Requirements connect this part of the overall design process to the rest of the design process

Design Activities and their products

Activity	Product	Product ID
Develop and Manage Power System Conceptual Architectures	Architecture Descriptions and List of Power and Propulsion System Conceptual Architectures	100
Perform Electric Power Load Analysis	EPLA – Power	200
	EPLA – Energy	210
	EPLA – In-Rush	220
	EPLA – Pulse	230
Develop and Maintain Load List	Electric Load List	300
Develop and Maintain Primary Power System Element Design	Primary Power System Element Design and Operating Methods	400
Develop and Maintain Zonal System Element Design	Zonal Power System Element Design and Operating Methods	500
Develop and Maintain Propulsion System Design	Propulsion System Design	600
Develop and Maintain Casualty Power System Design	Casualty Power System Design	700
Develop and Maintain Electrical Power System Concept of Operation and Propulsion System Concept of Operation	Electrical Power System Concept of Operation	800
	Propulsion Plant Concept of Operation	810
Develop and Maintain Electric Plant and Propulsion Control System Design	Electrical and Propulsion Control System Design	900
Perform Endurance Fuel and Annual Energy Usage Calculations	Endurance and Annual Fuel Calculations	1000
Perform Dynamic Simulation	Transient Analysis	1100
	Stability Analysis	1110
	Dynamic Response Analysis	1120
	Common Mode Current Analysis	1130
	Fault Current Analysis and Protective Device Coordination Study	1140
	Harmonic and Non-Fundamental Frequency Analysis	1150
	Thermal Analysis	1160

Perform Reliability Analysis	Reliability Analysis Report	1200
Perform Quality of Service Analysis	QOS Analysis Report	1300
Perform Vulnerability and Recoverability Analysis	Zonal Survivability Analysis Report	1400
	Compartment Survivability Analysis Report	1410
Perform Arc Flash Analysis	Arc Flash Analysis Report	1500
Perform System Safety Analysis and Hazard Analysis	System Safety and Hazard Analysis Report	1600
Perform Cybersecurity Analysis	Security Assessment Plan and Assessment	1700
Perform Product Support Analysis	Product support Analysis Report and Logistics Product Data	1800
Perform Human Engineering Analysis	Human Engineering Analysis Report	1900
Develop Specification Sections	Specification Sections (see Appendix C)	2000
Develop Power System Flexibility Strategy	Power System Flexibility Strategy	2100
Assess Power System Flexibility	Power System Flexibility Assessment	2200
Perform Electrical System and Propulsion System Development Test & Evaluation	DT&E Test Plan, Procedures, and Reports	2300
Develop Mission System - Power System Control Interface	PPD: Mission System - Power System Control Interface	2400
Perform Cost Engineering Analysis	Cost Engineering Analysis Report	2500
Develop Configurations	Configuration Descriptions	2600
Perform Set Reduction	Design Space Classification Report	2700

Some Design Activities can Produce Multiple Outputs

Labor Categories

- Amount of work that can be accomplished in a week for a given task depends on the number and mix of individuals of possibly multiple labor categories.
- Cost for different labor categories also varies.
- Used for resource loading the schedule

id	code	weekly rate	Description
0	eng_gen	$8,000.00	General Engineer
1	arch_sr	$8,000.00	Senior Power System Architect
2	arch_jr	$6,000.00	Junior Power System Architect
3	epla_sr	$8,000.00	Senior EPLA Engineer
4	epla_jr	$6,000.00	Junior EPLA Engineer
5	powr_sr	$8,000.00	Senior Power System Engineer
6	powr_jr	$6,000.00	Junior Power System Engineer
7	psim_sr	$8,000.00	Senior Power System Simulation Engineer
8	psim_jr	$6,000.00	Junior Power System Simulation Engineer
9	pwr_sim	$8,000.00	Power and Propulsion System Integration Manager
10	prop_sr	$8,000.00	Senior Propulsion System Engineer
11	prop_jr	$6,000.00	Junior Propulsion System Engineer
12	surv_sr	$8,000.00	Senior Survivability Engineer
13	surv_jr	$6,000.00	Junior Survivability Engineer
14	cost_sr	$8,000.00	Senior Cost Engineer
15	cost_jr	$6,000.00	Junior Cost Engineer
16	test_sr	$8,000.00	Senior Test Engineer
17	test_jr	$6,000.00	Junior Test Engineer
18	rma_sr	$8,000.00	Senior Reliability Engineer
19	rma_jr	$6,000.00	Junior Reliability Engineer
20	safe_sr	$8,000.00	Senior Safety Engineer
21	safe_jr	$6,000.00	Junior Safety Engineer
22	log_sr	$8,000.00	Senior Logistician
23	log_jr	$6,000.00	Junior Logistician
24	ctrl_sr	$8,000.00	Senior Control Engineer
25	ctrl_jr	$6,000.00	Junior Control Engineer

Design Structure Matrix (DSM)

Design data	Block Number	Subblock Number	Predecessor Block Number	100	300	400	500	2100	200	210	220	600	700	800	810	900	1000	1100	1110	1120	1130	1140	1150	1160	1200	1300	1400	1410	1500	1600	1700	1800	1900	230	2200	2300	2400	2500	2600	2700
100	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300	2	1	1	S	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	W	0
400	2	2	1	S	0	2	0	W	W	0	0	0	W	W	W	0	W	W	W	W	W	W	W	W	W	W	W	0	W	W	W	W	W	0	W	W	0	W	W	0
500	2	3	1	S	W	0	3	W	W	0	0	0	W	W	0	0	0	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	0	W	W	0	W	W	0
2100	2	4	1	S	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	3	0	2	S	S	0	0	0	5	0	0	0	0	W	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S	0
210	3	0	2	S	S	0	0	0	0	6	0	0	0	W	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S	0
220	3	0	2	S	S	0	0	0	0	0	7	0	0	W	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S	0
600	3	0	2	S	0	W	0	0	0	0	0	8	0	0	S	0	W	0	0	S	S	0	S	S	W	W	0	0	0	W	W	W	W	0	0	W	0	W	0	0
700	3	0	2	0	S	S	S	0	S	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	W	W	0	0	0	0	0	0	0	0	0	0	S	0
800	3	0	2	S	0	S	S	0	0	0	0	S	0	10	0	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S	0
810	3	0	2	S	0	S	0	0	0	0	0	S	0	0	11	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S	0
900	3	0	2	S	S	S	S	S	0	0	0	S	W	S	S	12	0	S	0	S	S	S	S	S	S	S	W	W	0	0	S	0	W	0	W	W	S	W	S	0
1000	3	0	2	0	0	S	W	0	S	0	0	S	0	S	S	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S	0
1100	3	0	2	0	S	S	S	0	0	0	0	S	0	S	S	S	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	W	0	0	S	0
1110	3	0	2	0	S	S	S	0	0	0	0	S	0	S	S	S	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	W	0	0	S	0
1120	3	0	2	0	S	S	S	0	0	0	0	S	0	S	S	S	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	W	0	0	S	0
1130	3	0	2	0	S	S	S	0	0	0	0	S	0	S	S	S	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	W	0	0	S	0
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1150	3	0	2	0	S	S	S	0	0	0	0	S	0	S	S	S	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	W	0	0	S	0
1160	3	0	2	0	S	S	S	0	0	0	0	S	0	S	S	S	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	W	0	0	S	0
1200	3	0	2	0	0	S	S	0	0	0	0	S	W	S	S	S	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	S	0
1300	3	0	2	0	S	S	W	0	S	S	S	0	0	S	0	0	0	W	W	0	0	0	W	0	S	22	0	0	0	0	0	0	0	S	0	0	0	0	S	0
1400	3	0	2	0	S	S	S	0	S	0	0	S	S	S	S	W	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	S	0
1410	3	0	2	0	S	S	S	0	S	0	0	S	S	S	S	W	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	S	0
1500	3	0	2	0	0	S	S	0	0	0	0	S	0	S	S	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	S	0
1600	3	0	2	0	0	S	S	0	0	0	0	S	W	S	S	S	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	S	0
1700	3	0	2	0	0	S	S	0	0	0	0	S	W	S	S	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0	0	0	S	0
1800	3	0	2	0	0	S	S	0	0	0	0	S	W	S	S	S	0	0	0	0	0	0	0	0	S	0	0	0	0	0	0	28	S	0	0	0	0	0	S	0
1900	3	0	2	0	0	S	S	0	0	0	0	S	W	S	S	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	S	0
230	3	0	2	S	S	0	0	0	0	0	0	0	0	W	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	S	0
2200	3	0	2	S	0	S	S	S	S	0	0	S	0	0	0	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	S	0
2300	3	0	2	0	0	S	S	0	0	0	0	S	W	0	0	W	0	W	W	W	W	W	W	W	0	0	0	0	0	0	0	0	0	0	0	32	0	0	S	0
2400	3	0	2	W	W	W	W	0	0	0	0	0	0	S	0	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0
2500	3	0	2	0	0	S	S	0	0	0	0	S	W	0	0	S	0	0	0	0	0	0	0	0	S	0	0	0	0	0	0	S	0	0	0	0	0	34	S	0
2600	3	0	2	S	W	S	S	0	S	0	0	S	W	0	0	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	S
2700	3	0	2	0	0	0	0	0	S	S	S	0	0	0	0	0	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	0	S	S	36

Iteration is required and challenging with traditional scheduling tools

A

02epla: Perform Electric Power Load Analysis

Description

- Perform a generalized EPLA
- Determine required power and energy rating of power system components
  - Power Generation
  - Power Conversion Modules
  - Energy Storage Modules
  - Power Distribution
- Power Capacity Analysis
  - Traditional EPLA
  - Load Flow Analysis (for main bus)
  - 24 Hour average load
- Energy Storage Analysis
  - Adequacy of energy and power rating based on quasi-steady state analysis
- In-Rush Current Analysis
  - Adequacy of sources to provide in-rush current to loads based on quasi-steady state analysis
- Pulsed Load analysis
  - Adequacy of sources and distribution to provide pulsed power to loads. Based on quasi-steady state analysis.

Inputs

- R020 Ship Operating Conditions(High)
- R030 Margin and Service Life Allowance Policy (High)
- R040 Ambient Condition Profile (Low)
- 100 List & Description of Power and Propulsion System Conceptual Architectures (High)
- 300 Load List (High)
- 800 Electrical Power system CONOPS (Low)
- 810 Propulsion System CONOPS (low)
- 2600 Configuration Descriptions (High)

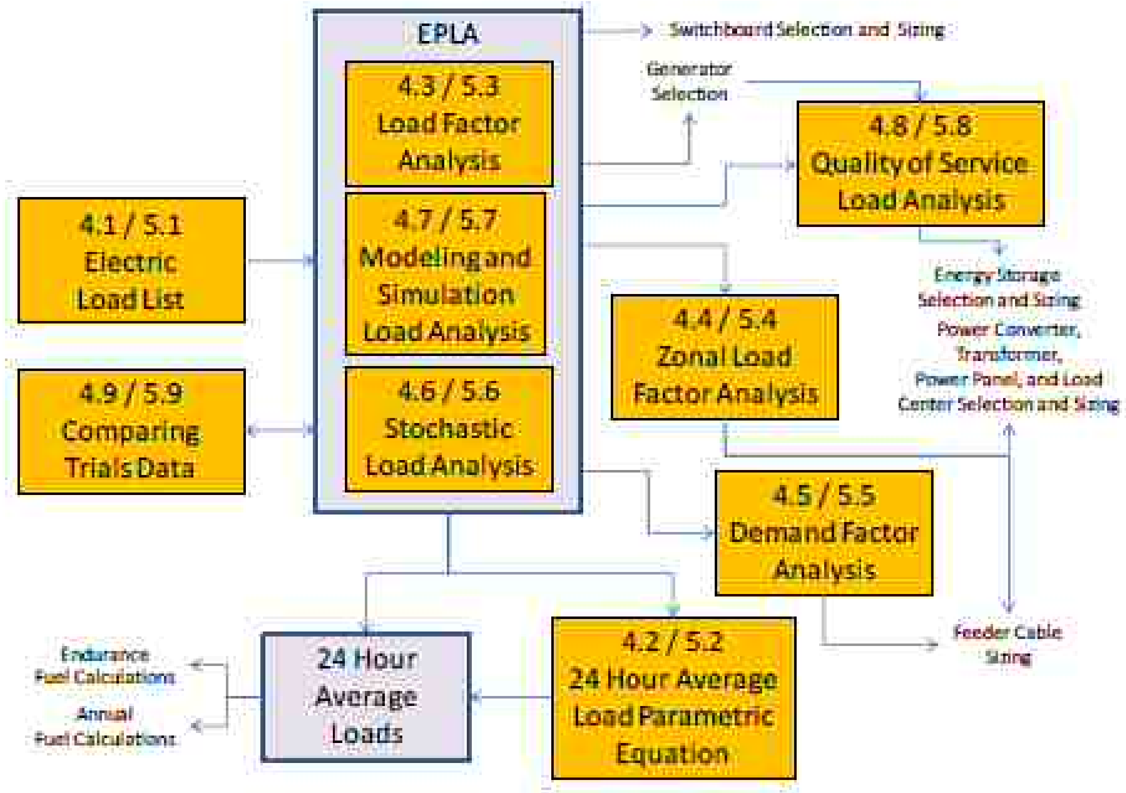
Outputs

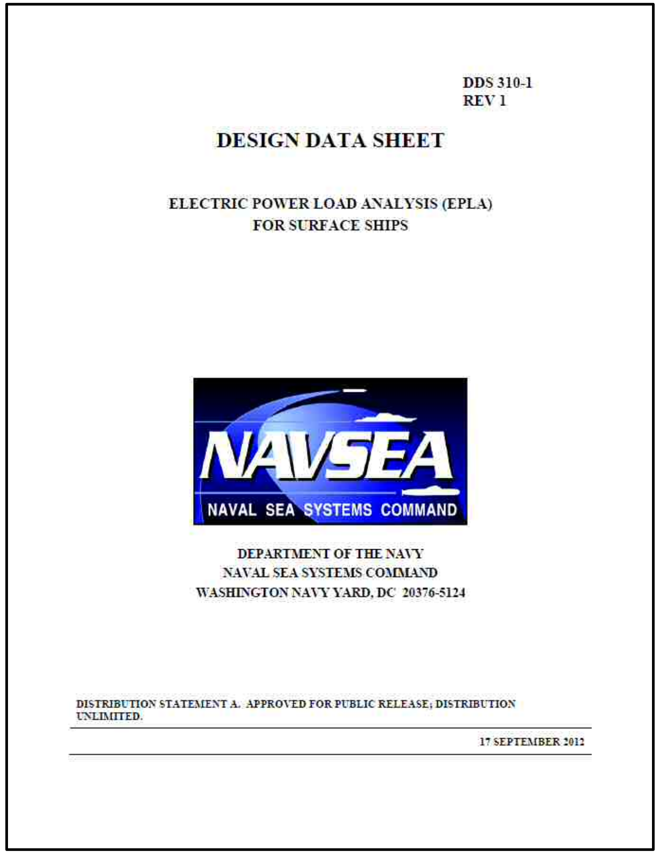
- 200 EPLA – Power
- 210 EPLA – Energy
- 220 EPLA – In-Rush
- 230 EPLA - Pulsed

References

- T9070-A3-DPC-010/310-1
- T9300-AF-PRO-020 Revision 1
- Preliminary Electrical System DPC MVDC Supplement

T9070-A3-DPC-010/310-1 (AKA DPC 310-1)





DDS 310-1
REV 1

DESIGN DATA SHEET

ELECTRIC POWER LOAD ANALYSIS (EPLA)
FOR SURFACE SHIPS

NAVSEA
NAVAL SEA SYSTEMS COMMAND

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON NAVY YARD, DC 20376-5124

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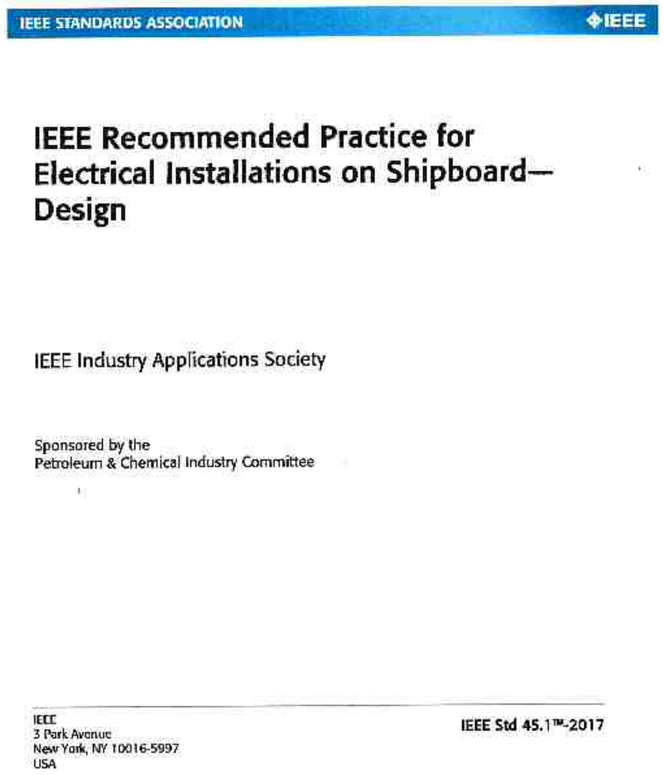
17 SEPTEMBER 2012

Viewgraph from “Electric Load Modeling”, Dr. Norbert Doerry and Dr. John Amy Jr, ASNE Intelligent Ships Symposium, Philadelphia PA, April 9-10, 2019.

IEEE Std 45.1-2017 Annex B (Normative)

- Operating Conditions
- Groupings
- Load Factors
- Margins
- Load Analysis
- 45.1 is primarily intended for later phases of ship design; however, Annex B is cited in IEEE Std 45.3-2015 for earlier phases of ship design.



IEEE STANDARDS ASSOCIATION — IEEE

IEEE Recommended Practice for Electrical Installations on Shipboard—Design

IEEE Industry Applications Society

Sponsored by the
Petroleum & Chemical Industry Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 45.1™-2017

What is Electric Plant Load Analysis (EPLA)?

- Used as an input for determining the power requirements for electrical generation, energy storage, and power conversion components and equipment and current requirements for electrical distribution equipment and components.
- Used to develop 24-hour average electrical load estimates for calculating fuel endurance and annual fuel consumption.
- Two steps
  - Identifying, compiling, estimating, and categorizing all of the electrical loads on a ship
  - Using an algorithm to combine the estimated loads to determine the design requirements for electrical system components and equipment

Varying Ambient Conditions – Varying Loads

- Default conditions that are tailored based upon specific ship requirements
  - 25% of time at 10 °F with 95% relative humidity
  - 50% of time at 59 °F with 95% relative humidity
  - 25% of time at 100 °F with 40% relative humidity
- These are conditions outside of the ship (weather).
  - Heating in colder regions is a significant load.
  - Cooling in hotter regions is a significant load.
- Equipment which operates within the ship and generates heat must always be cooled.

Varying Ship Operational Conditions – Varying Loads

- Port – Vessel dockside receiving power from shore facilities or ship main generators.
- Anchor − Vessel is at anchor and powered by ship main generators.
- Cruise − Vessel is underway normally transiting from one location to another and powered by ship main generators.
- Functional − Vessel is underway performing its designed function(s), if other than cruise, and powered by ship main generators. Name can be changed for specific function.
- Emergency – Vessel in emergency status with ship main generators unavailable supplying only emergency loads, as defined by regulatory bodies, from the emergency generator or emergency energy storage system (e.g., UPS).
- Safe return to port − As required for certain passenger ships, a condition where a ship has suffered damage not exceeding the fire casualty threshold as defined in SOLAS. The ship should be capable of returning to port using its own power, with all essential systems operational and while providing a safe area(s).

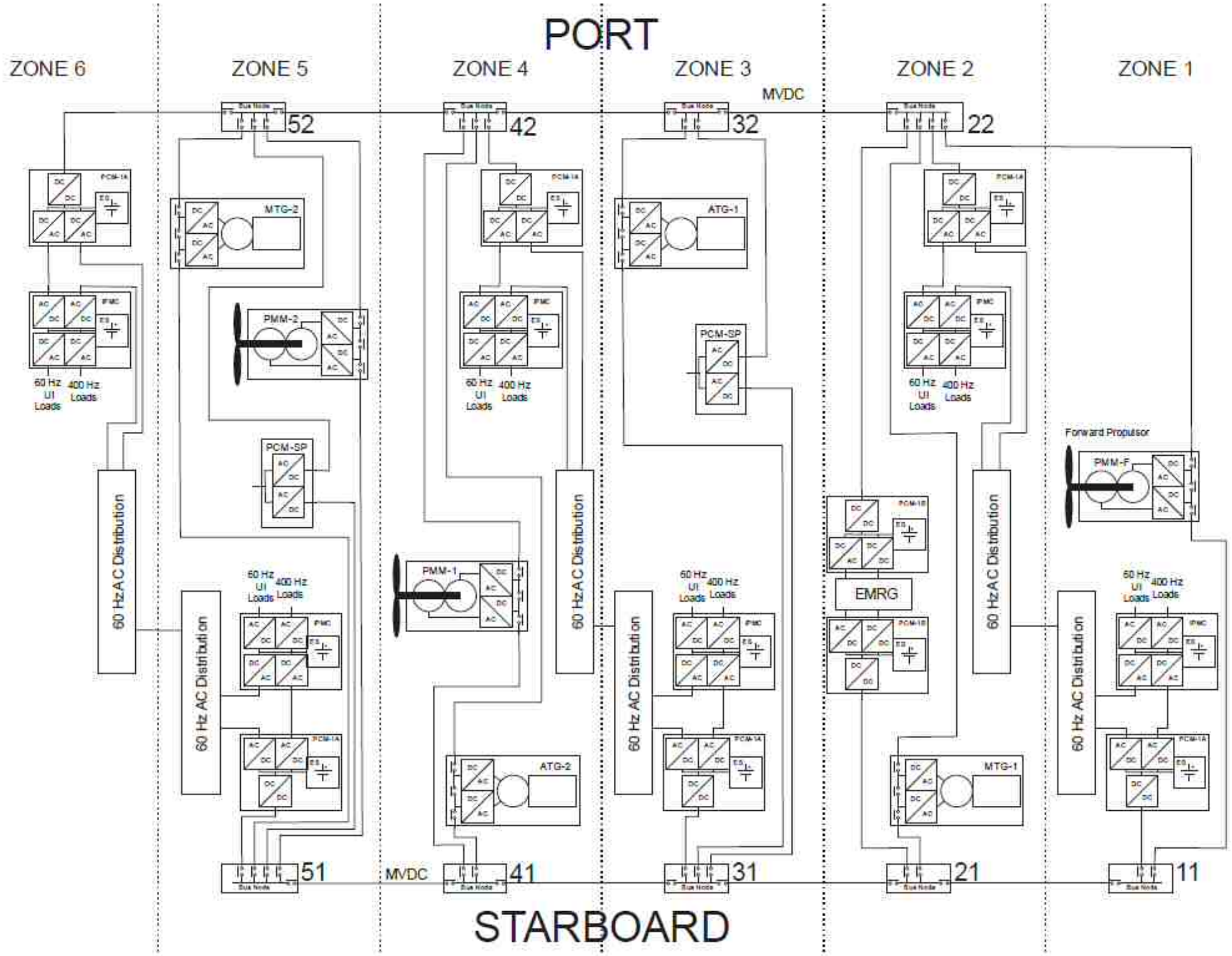
Time Scale is Important

- Seconds (MIL-E-7016F suggests 5 seconds)
  - Thermal limit for power electronics
- Minutes (MIL-E-7016F suggests 5 minutes)
  - Thermal limit for copper – steel based equipment
- 24 hours
  - Annual Fuel Consumption

Viewgraph from “Electric Load Modeling”, Dr. Norbert Doerry and Dr. John Amy Jr, ASNE Intelligent Ships Symposium, Philadelphia PA, April 9-10, 2019.

Levels of Aggregation

- The fewer the loads in an aggregation the greater attention need be placed on variance
- Zonal load factor analysis adjusts for this variability
- Stochastic methods or modeling and simulation methods may be more appropriate



Viewgraph from “Electric Load Modeling”, Dr. Norbert Doerry and Dr. John Amy Jr, ASNE Intelligent Ships Symposium, Philadelphia PA, April 9-10, 2019.

Electric Plant Load Analysis (EPLA) – The Essential How-To …

- Start with a list of loads – the ‘connected load’
- Determine which portion of the ship power system is under consideration
  - “Entire ship set of loads” – fuel consumption, generating capacity
  - “Zonal set of loads” – conversion / distribution equipment capacities
  - Other subsets …
- Develop appropriate load factors for the operating conditions / time scale of interest
- Do the math …

Example Analysis Summary Sheet

From IEEE Std 45.1-2017 Annex B (Normative)

Table B.2 —Typical Example of a Load Analysis Summary Sheet

GROUP	SYSTEM/EQUIPMENT	CONN (kW)	ORT (kW)	ANCHOR (kW)	SUMMER CRUISE (kW)	WINTER CRUISE (kW)	EMERG (kW)
100	PROPULSION						
200	BATTERIES AND BATTERY CHARGERS						
300	POWER CONVERSION EQUIPMENT						
400	LIGHTING						
500	ELECTRONICS						
600	NAVIGATION SYSTEMS						
700	AUXILIARIES						
800	HEATING VENTILATION AND AIR CONDITIONING SYSTEMS						
900	DECK MACHINERY						
1000	FOOD SERVICES						
1100	WORKSHOP/LAUNDRY EQUIPMENT						
	KW TOTALS - NO GROWTH MARGIN						
	DETAIL DESIGN & CONSTRUCTION MARGIN (KW)						
	OTHER MARGINS, IF APPLICABLE (KW)						
	KW TOTALS - WITH MARGINS						

Consider Load Factors – Different Conditions

From IEEE Std 45.1-2017 Annex B (Normative)

Table B.11— Typical GROUP 800 Heating Ventilating and Air Conditioning Systems Load Factors

Group	System/Equipment	In Port	At Anchor	Summer Cruise	Winter Cruise	Emergency
800-1	AC Compressor	0.7	0.7	0.7	0.3	0.0
800-2	Cargo Hold Supply Fan	0.9	0.0	0.0	0.0	0.0
800-3	Cargo Hold Exhaust Fan	0.9	0.0	0.0	0.0	0.0

Table B.12— Typical GROUP 900 Deck Machinery Load Factors

Group	System/Equipment	In Port	At Anchor	Summer Cruise	Winter Cruise	Emergency
900-1	Anchor Windlass	0.0	0.0	0.0	0.0	0.0
900-2	Capstan	0.0	0.0	0.0	0.0	0.0
900-3	Cranes	0.0	0.0	0.0	0.0	0.0

Table B.13— Typical GROUP 1000 Food Services Load Factors

Group	System/Equipment	In Port	At Anchor	Summer Cruise	Winter Cruise	Emergency
1000-1	Trash Compactor	0.2	0.2	0.2	0.2	0.0
1000-2	Juice Dispenser	0.3	0.3	0.3	0.3	0.0
1000-3	Range/ Convection Oven	0.3	0.3	0.3	0.3	0.0
1000-4	Deep Fat Fryer	0.3	0.3	0.3	0.3	0.0
1000-5	Refrigerator	0.3	0.3	0.3	0.3	0.0

Electric Plant Load Analysis (EPLA) – *Some* of the Challenges …

- Earlier in the ship design process, details with regards to loads and power system equipment is unknown and / or uncertain.
    - Some load systems may still be in design and development.
    - Load system capacities may yet to be finalized, affecting electric power draw.
- The design may incorporate novel technologies, novel equipment, and / or novel design processes.
    - Integration of energy storage
    - ‘Smart controls’ – load and power system equipment
- The ship design may be changing significantly between design iterations.
    - Arrangements revisions may move loads into different zones, leading to re-aggregation.
    - Producibility considerations may lead to changing zonal boundaries, leading to re-aggregation.

Energy Storage

- ESM-F1: Backup up power for uninterruptible loads during fault clearing and system reconfiguration
- ESM-F2: Backup up power upon loss of online power generation module
- ESM-F3: Emergency starting of a PGM
- ESM-F4: Load Leveling and preventing PGM over load
- ESM-F5: Provide primary power

An Energy Storage Module can be used to fulfill multiple functions, but must have sufficient capacity for any likely scenario.

Energy Storage capacity issues

- Required Power
  - Discharge – based on function and load requirements
  - Charge – Impacts sizing of supplying power system components
- Required Energy
  - Based on function and load requirements
  - If supporting multiple functions, must determine amount of energy storage capacity for most stressing likely use case.
- Required control system functions
  - Logic for energy storage usage should be documented in Electrical Power System Concept of Operations (EPS-CONOPS)

Energy Storage Analysis

- ESM-F1 Back up Power – Fault clearing - reconfiguration
  - Quasi-steady-state analysis
  - Determine required power and maximum duration of power interruption
- ESM-F2 Back up Power - Loss of PGM
  - Quasi-steady-state analysis
  - Determine required power, time to shed loads, and maximum duration of power interruption
- ESM-F3 Starting of PGM
  - Quasi-steady-state analysis
  - Determined required power and maximum time to start PGM
- ESM-F4 Load Leveling and preventing PGM overload
  - Understanding load variance on time scales appropriate for application
    - Slow Dynamic Response of PGM – on order of 10 ms
    - Pulsed Loads – Pulse magnitude and current ramp rate – then use Quasi-steady-state analysis
  - Determine required power and energy to implement function
- ESM-F5 Primary Power
  - Quasi-steady-state analysis
  - Determine required power and minimum time to supply power.

In-Rush Current

- Loads can have large in-rush currents (7 to 10 or more times rated current)
  - Charging of input capacitors
  - Short term saturation of magnetics.
- Power Electronics may not have adequate capability (3 or less times rated current) to provide in-rush current to loads.
  - May current limit resulting in voltage falling below transient voltage limits
  - May shut down on over-load
- Small Generator Sets may not have capability to simultaneously provide in-rush current to multiple transformers.
  - Voltage may fall below transient voltage limits
  - May shut down on over-load
- Must estimate in-rush current requirements of loads and determine worst case combination of in-rush currents to compare with source capability.
- If sources unable to provide sufficient in-rush current, possible solutions include:
  - Increasing capacity of sources (over-sizing)
  - Controlling in-rush of loads through methods such as pre-charge circuits
  - Prevent multiple loads from coming on line at the same time via controls

Know early, when corrective action is relatively easy, if in-rush currents are a problem.

Pulsed Load

- Establish feasibility for the power system being capable of serving pulsed loads while maintaining power quality to other loads.
  - Power Generation capacity.
  - Required current ramp rates vs power system capability
    - PGM ramp rate capability
    - Energy Storage ramp rate capability
    - Distribution system inductance limitations on ramp rate.
      - Maximum current ramp rate allowed without voltage dropping below transient limits.
- Possible design choices if power system not capable of achieving required current ramp rate
  - Reduce system inductance through cable selection.
  - Insert energy storage with proper capability near the pulsed load.
  - Choose PGM with greater ramp rate capability
  - Use “Dynamic Braking Resistors” dynamically to reduce ramp rates seen by the PGM.
  - Choose system architectures to minimize need for current reversals during a pulse

Questions?

BREAK

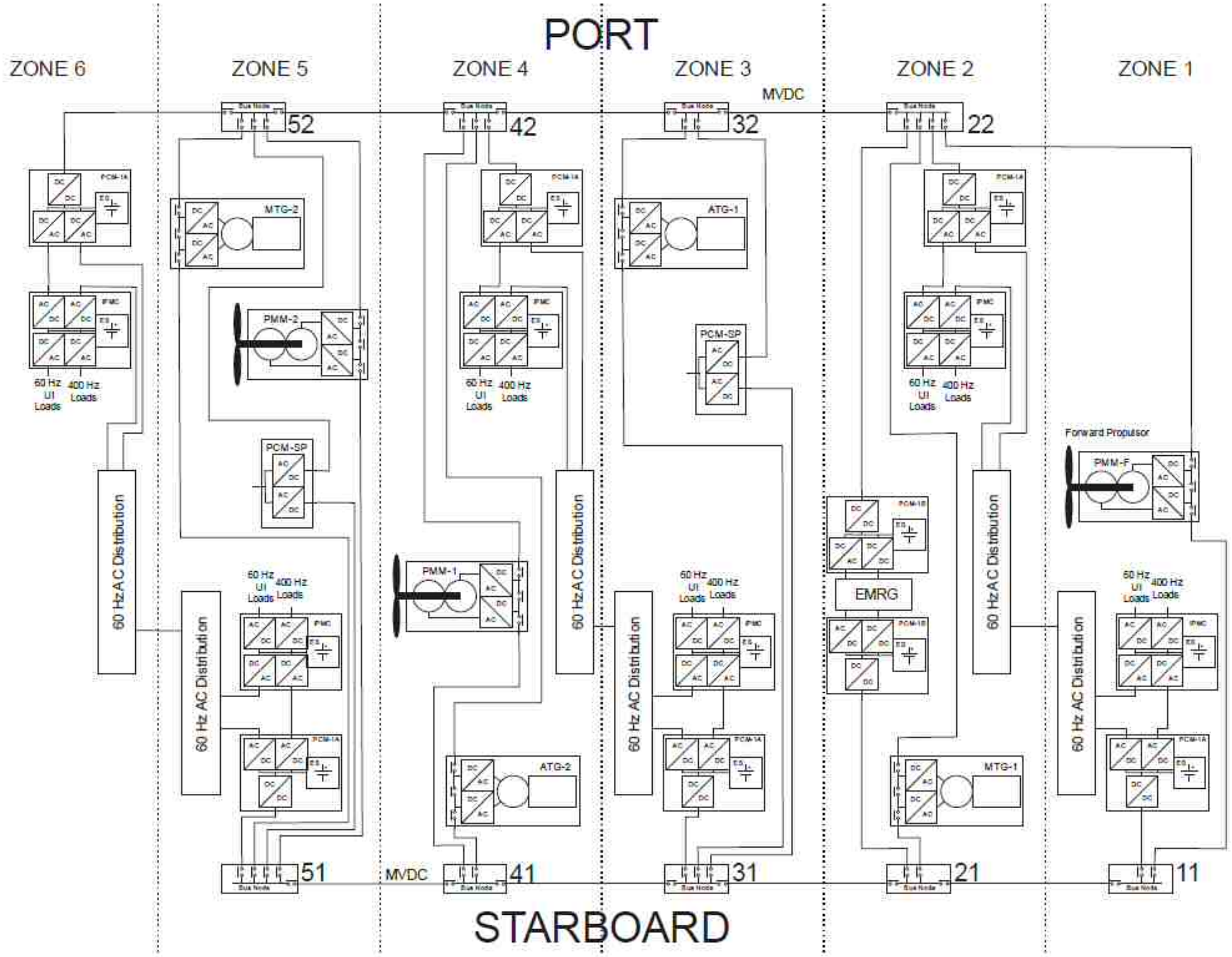
Requirements

Power System Requirements	R010
Ship Operating Conditions	R020
Margin and Service Life Allowance Policy	R030
Ambient condition Profile	R040
Machinery Arrangements	R050
General Arrangements	R060
Master Equipment List	R070
Combat Systems Design	R080
Other Distributed System Design	R090
Speed Power Curve	R100
Survivability Requirements	R110
QOS Requirements	R120
Endurance Requirements	R130
Operational Profiles	R140
System Safety Plan	R150
Security Controls (from Risk Management Framework)	R160
Product Support Analysis Plan	R170
Flexibility Requirements	R180
Build Plan	R190
Zone Boundaries	R200
SDM Guidance	R210

Requirements connect this part of the overall design process to the rest of the design process

Levels of Aggregation

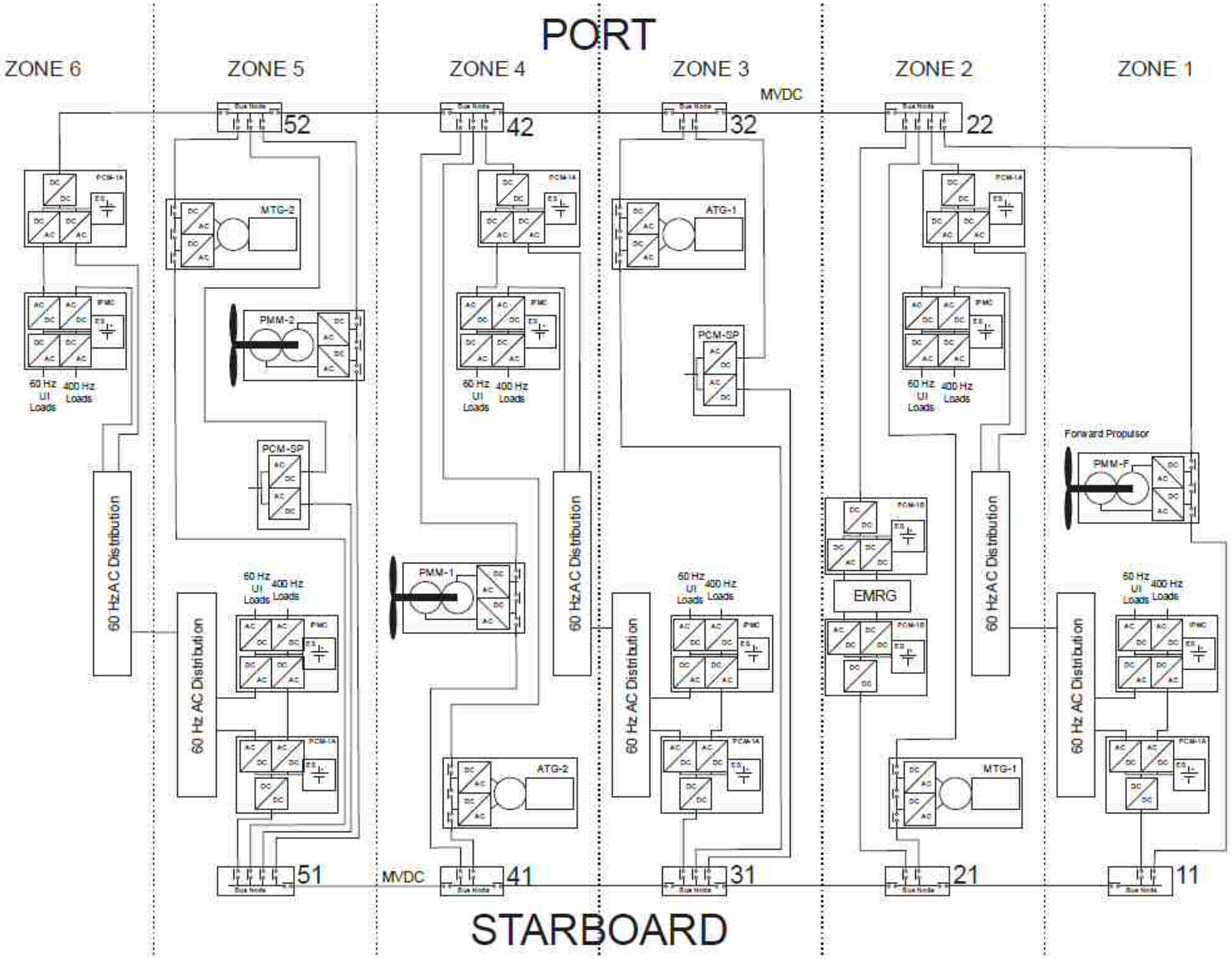
- The fewer the loads in an aggregation the greater attention need be placed on variance
- Zonal load factor analysis adjusts for this variability
- Stochastic methods or modeling and simulation methods may be more appropriate



Viewgraph from “Electric Load Modeling”, Dr. Norbert Doerry and Dr. John Amy Jr, ASNE Intelligent Ships Symposium, Philadelphia PA, April 9-10, 2019.

Within the Zones …

- Zonal load factor - The load factor of a load adjusted (if necessary) to account for load variability for the purpose of determining the required rating of zonal power systems elements.
- Zonal operating load - The product of a load's zonal load factor and connected load.
- Zonal power system element - A zonal power system element is one of the following: zonal power conversion equipment, load center, bus feeders, zonal transformers, or zonal energy storage. Small distribution transformers are not considered zonal power system elements.



Where are the users of electricity located?

- Arrangements:
  - are the physical representation of the ship.
  - are the allocation of functions to area and volume
  - interface with nearly all aspects of the ship design
  - are the supreme integration task
  - are often the configuration control for the ship, particularly during design
- When developing ship arrangements, the objectives are to:
  - balance space available with functional requirements
  - maximize overall ship effectiveness
  - validate the design
- As is always the case in ship design, arrangements:
  - must balance competing functions
  - should be performed in concert with the ship's design philosophy
  - require iteration
- Most naval ships are space critical (volume limited) and their size and resulting cost are governed, in part, by the spatial requirements.

Arrangements Integration Priorities

In Order of Precedence

- Mission Area / Combat System
  - Weapons, Flight Deck, Well Deck, Sensors, Bridge, Ship Control, Helo Hangar, Off-Board Sensors
- Machinery
  - Main Machinery Rooms, Auxiliary Machinery Rooms, Shafts, Propellers, Uptakes, Intakes
- Human Support
  - Staterooms, Sanitary, Galley and Messing, Crew Stowage
- Ship Support
  - Damage Control, Storerooms, Issue Rooms, Paint Locker, Ship's Offices, Access
- Tankage
  - Fuel Oil, Ballast, Potable Water, Lube Oil
- Unassigned
  - Margin

Arrangements Interfaces

- Topside Design
  - Sensor Placement
  - Weapons and Magazine Placement
  - Cable and Waveguide Lengths
  - Structural Supports
  - Uptakes and Intakes
  - UNREP Stations
- Survivability
  - Subdivision
  - Fire/CPS/HVAC Zones
- Ship Strength
  - Bulkhead Locations
  - Deck Height and Hull Depth
- Producibility
- Trim and Stability
  - Tankage Locations
  - Equipment Centroids
- Crew Size
- Ship Size and Cost

General Arrangements: Principles

- Physical Integration
- Functional Integration (Adjacency) - OPNAV INST 9640.1, Table 1
- Operational Separation (Separation) - OPNAV INST 9640.1, Table 2
- Iterate

General Arrangements: Approach

- Develop Ship Design Philosophy, Requirements, and Constraints
  - TLR/ORD/Performance Specification
  - Enables prioritization of functions
- List Major Functions and Compartments
  - From the ORD, write down everything the ship must do
  - List systems, subsystems, and major components to support functions (SSCS)
  - Look at past designs and experience to develop a comprehensive and improved list
- Determine Arrangement Requirements
  - Sizes of equipment
  - Sizes of spaces (galley, staterooms, etc.)
  - Deck area requirements
  - Access/passageway locations, sizes, and widths
  - Adjacency requirements (Table 1 of NAVSEA Design Practices and Criteria Manual)
  - Separation requirements (Table 2 of NAVSEA Design Practices and Criteria Manual)
  - Rules
    - Vital Spaces
    - Subdivision
    - Access

    } GENSPECS 070,071 / NAVSEA Design Practices & Criteria Manual Chap 070
    - Margin (10% for Preliminary Design)
    - Habitability and human support **- OPNAVINST 9640.1, GENSPECS**

Survivability Considerations

- Arrangements address "Vulnerability" aspect of Survivability
- Three principal means of increasing survivability through arrangements:
  - Locate Vital Spaces in Protected Areas
  - Separate Vital, Redundant Systems
  - Consolidate Vital, Singular Systems
- Zonal Ship Configuration
  - Minimize longitudinal extent of series dependent systems
  - Group series dependent systems in self-sufficient functional zones (enclaves)
    - Functional components
    - Electric power
    - HVAC/CPS
    - Cooling water
    - Compressed Air
    - Firefighting and Damage Control (Fire main/AFFF, PKP, Halon/DC Lockers)
    - Command and Control
  - Maximize separation of parallel, redundant systems
  - Minimize connectivity across zone boundaries
  - Optimize routing/architecture of distribution systems for:
    - Reliability, maintainability, availability (RMA)

Questions?