Artificial Intelligence Utilization for Ship Design Optimization

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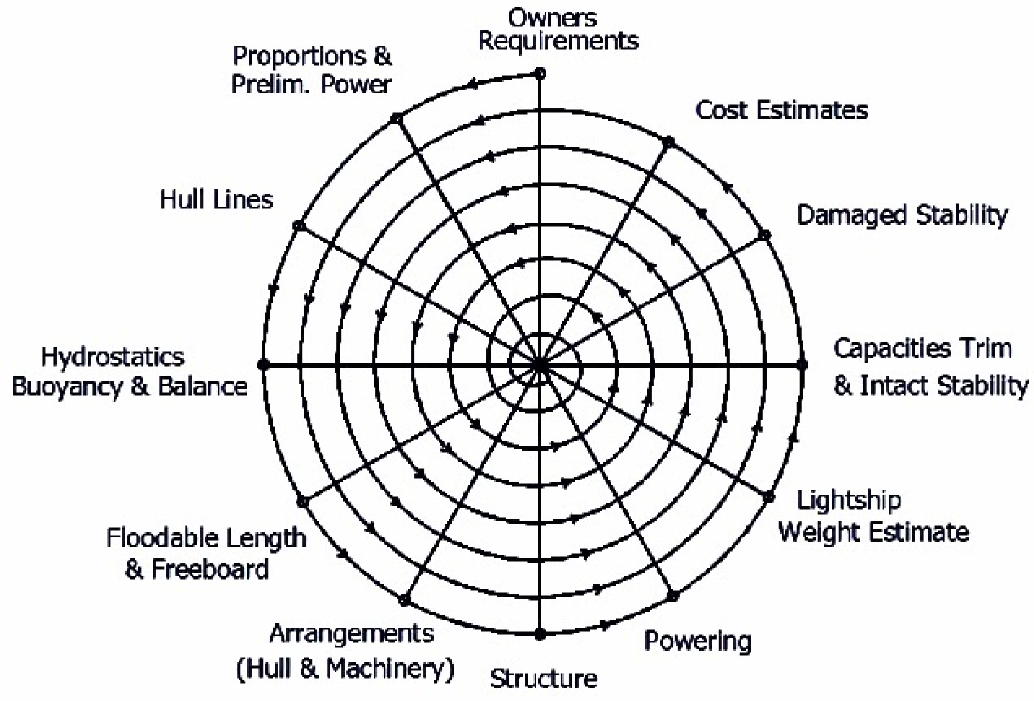
Background and Problem Statement

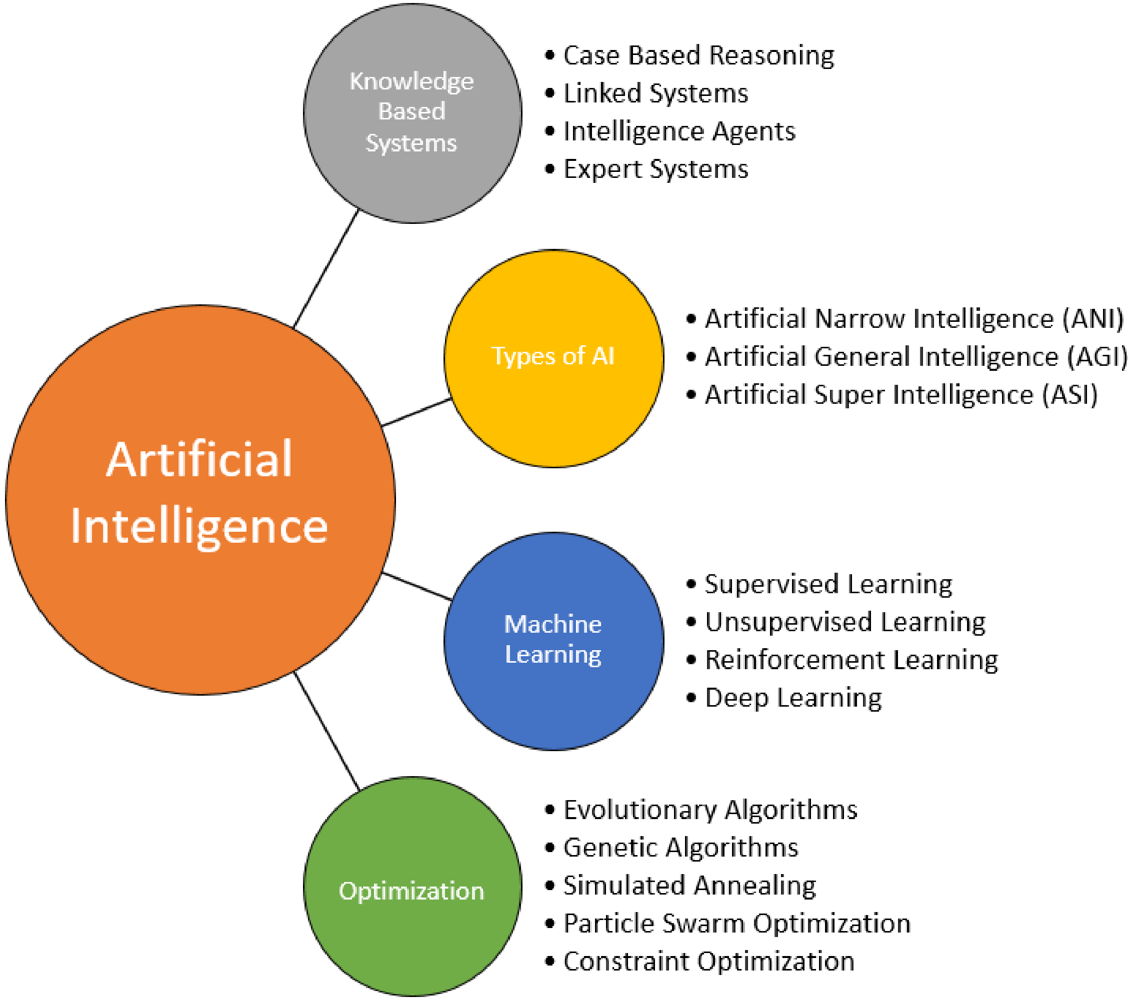
- Current Ship Design processes and methods leave opportunities for design spiral which lead to schedule impacts, cost increase, and reduced performance across the industry.
- Utilizing Artificial Intelligence (AI) to support or substitute legacy ship design methods offers significant impact to overall reduction of size, weight, power, and cost (SWAP-C) metrics.



Machinery Room Arrangement Hypothesis

- With efforts to focus on the feasibility of AI utilization on ship design improvement, Machinery Room arrangement was selected for evaluation for future development.
- AI system implementation can improve ship Machinery Room arrangements and reduce overall SWAP-C and program metrics when utilized for:
    - New ship design and Machinery Room arrangement generation
    - Existing design & parent design optimization

Artificial Intelligence Considerations

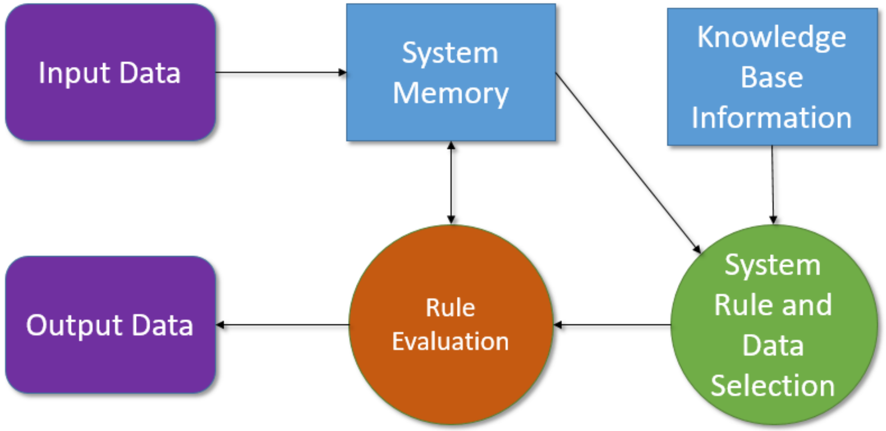


- Although AI continues to develop and expand, general knowledge of structure and utility is critical for evaluation, future design, and implementation.
- Breaking down analysis into the four categories depicted allows for high level understanding and selection of various aspects.
- From overall Types of AI to specific Optimization methods, all current and developing AI technologies are classified as possible sources.

Knowledge-Based Systems

- Knowledge-Based Systems are simpler ANI based concepts that operate based on software and human participation.
- Systems are given databases, rules, and criteria that are used as sources for comprehension and evaluation before outputting a solution based on desired output.
- Common examples:
  - Intelligent tutoring systems
  - Medical diagnosis systems
  - Natural Language Processing Systems

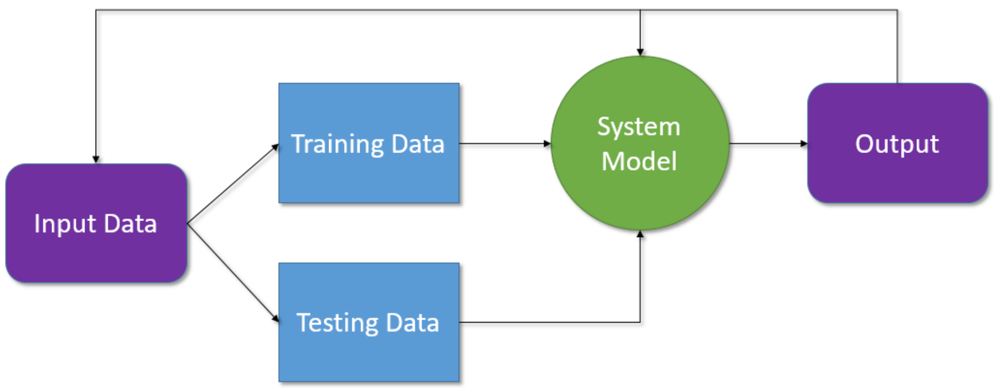
Knowledge-Based System Structure



Machine Learning (ML)

- Algorithm based AI systems structured for intelligent evaluation and decision making without human identified rules, patterns, or criteria to operate based off.
- Allows for programs to use data to learn and improve without explicitly being programmed to do so.
- Categorized based off Learning capabilities:
  - Unsupervised Learning
  - Supervised Learning
  - Deep Learning

Supervised ML Workflow



AI Optimization Methods Focus

Stochastic Methods

- Performs iterations of accepting or rejecting random outputs, only converging on a solution when no further improvements are identified.
  - Simulated Annealing
  - Evolutionary Algorithms

Constraint Optimization

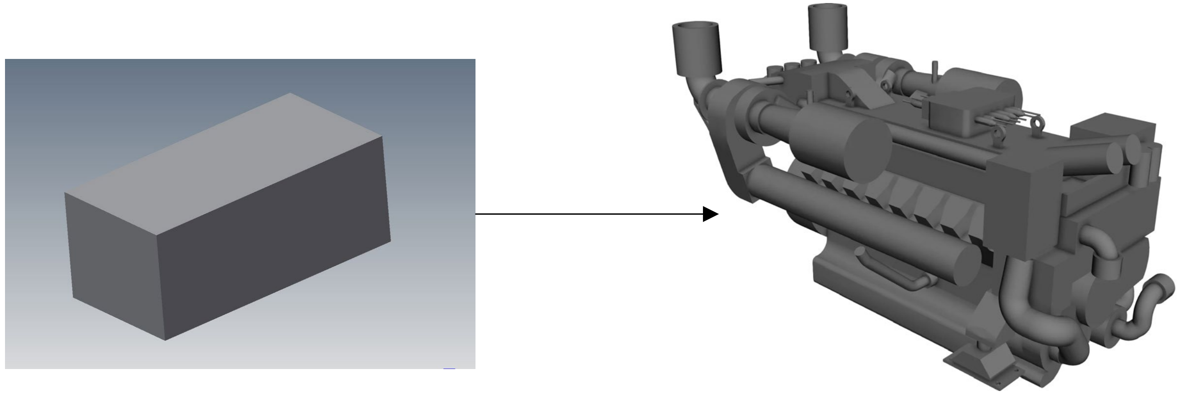
- Algorithms operate based on strict constraints or limitations that are evaluated using tradeoff and dominance analytics.
  - Multiobjective optimization

Population Methods

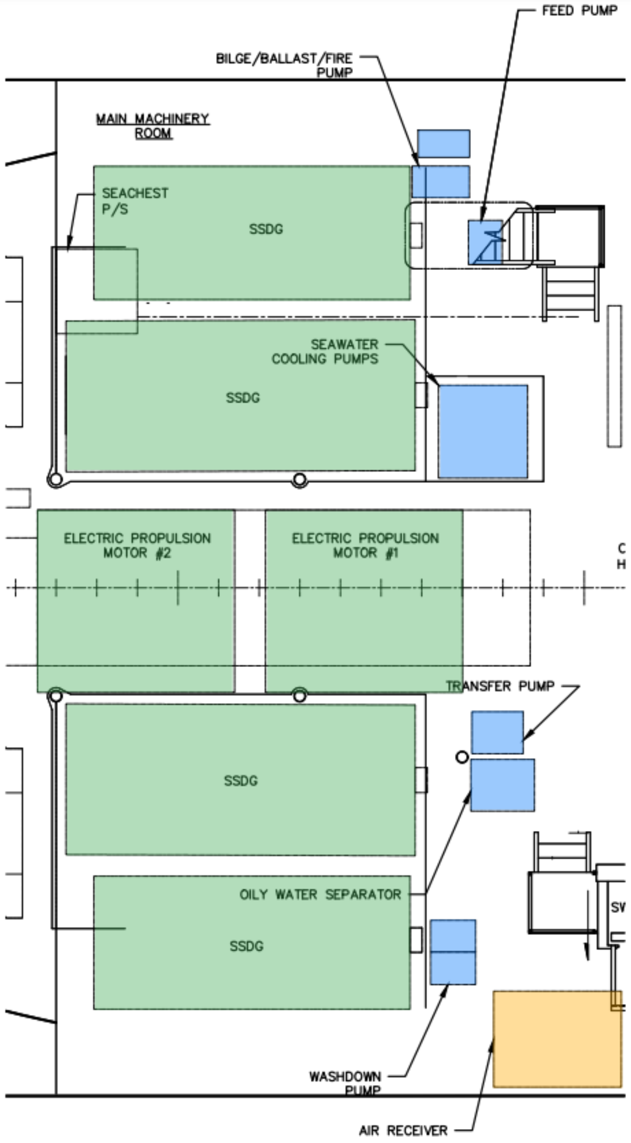
- Utilize existing population and desired design point to reach a global optimum or unanimous optimized solution.
  - Genetic Algorithms
  - Particle Swarm Optimization

Legacy Machinery Arrangement Generation

- Machinery arrangement generation typically begins with technical requirements at the ship level such as:
  - Power generation
  - Speed
  - Endurance
  - Fuel Storage
  - Maneuverability
  - Environmental Impacts
  - Berthing
  - Operating Environment
  - Specification/Standard Compliance
- Preliminary arrangements begin with machinery typically displayed using generic space reservations that evolve to detailed models.
  - Legacy arrangement tools involve AutoCAD, Rhino, ShipConstructor, SolidWorks, and more.



Machinery Arrangement Tiered Example



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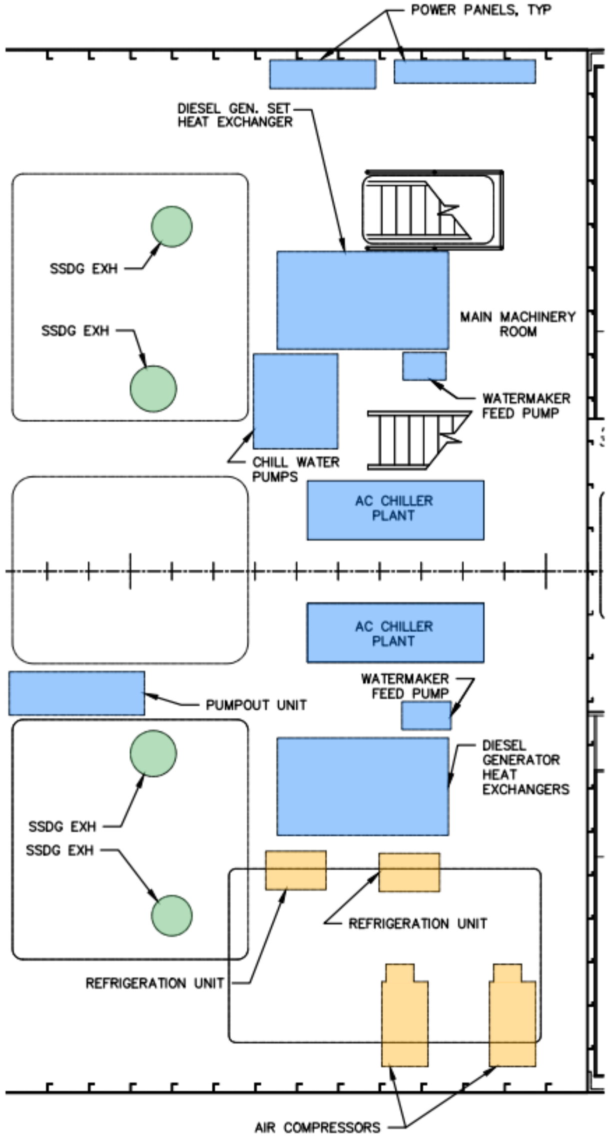


Mezzanine

Machinery Tiers

Tier 1
Propulsion Engines
Ship Service Generators
Combing/Reduction Gears
Steering Gear & Tiller

Tier 2
Fuel Service & Conditioning Skids
Lube Oil Service & Conditioning Skids
Desalination Plant
Propulsion Shafting & Bearings
Seawater Cooling Pumps
Fire-main Pumps
Hydraulic Power Units

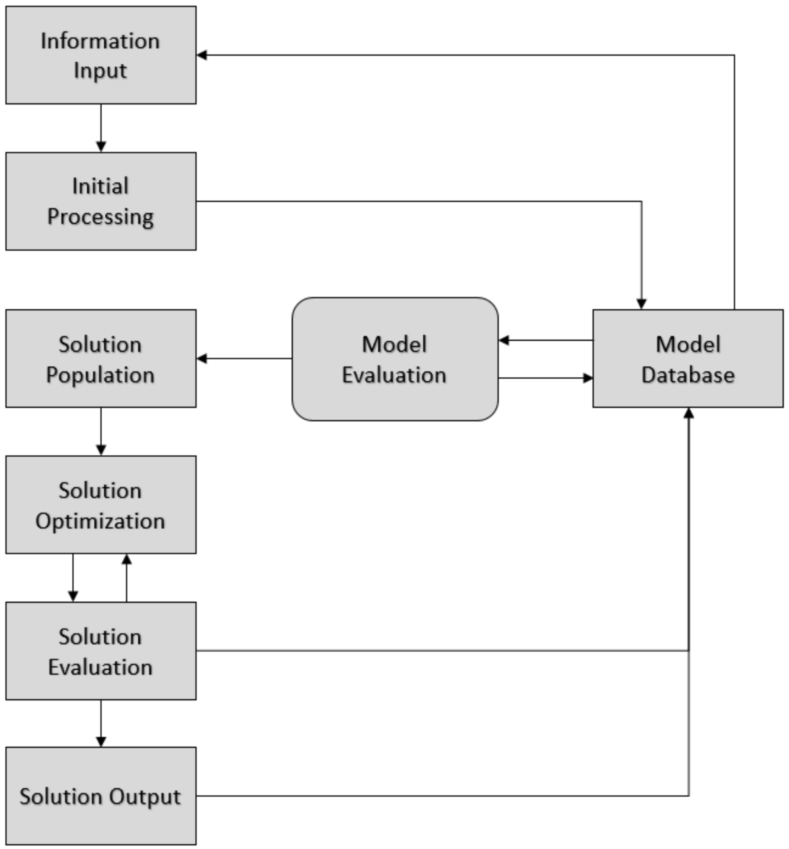
Tier 3
Air Compressors
Switchboards & Transformers
Sewage treatment plant
Shop Machinery (Lathes, Drill Presses, etc.)
Fan Coils
Water Heaters

Legacy Machinery Arrangement Process Complications

- As Machinery Arrangements require efforts throughout the duration of multiple ship design phases, typical complications seen include:
  - Density Complications – unexpected growth
  - Interference Issues – definition reveals interference complications
  - Unmet compliance to specifications and authorities
  - Movement/Adjustment
    - Installation and removal route issues
    - Supporting/auxiliary system rework
    - Overall ship performance and stability
    - Reduced system performance
    - Machinery maintenance and access clashes
    - Trickle-down effect to other machinery

AI Process Structure for Improvement

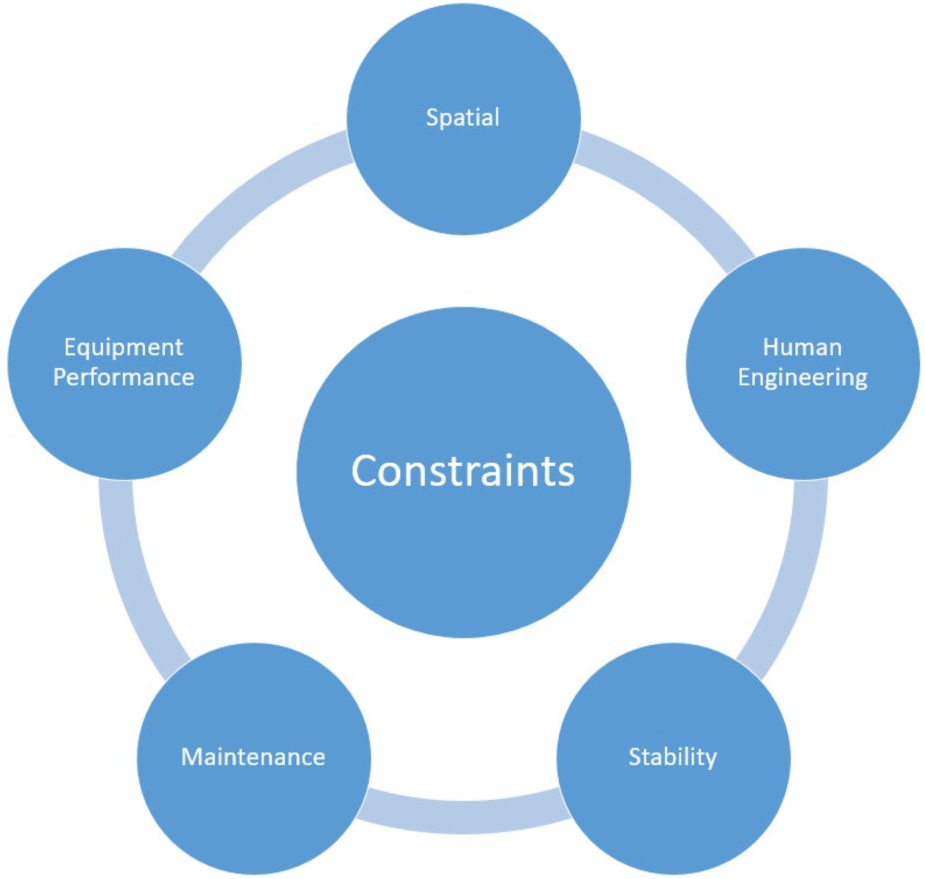
- To improve the Machinery Arrangement process, a culmination of multiple AI techniques with heavy reliance on constraints can be evaluated.
    - Culmination of genetic algorithm, constrain methods, machine learning, and optimization engines.
    - Information is inputted, absorbed, sourced, and processed.
    - The Model Database serves as a repository for all data.
    - Model evaluation works to produce a population for optimization processing.
    - Once the engine converges based on tradeoff and performance limitations, a solution is outputted and also stored back in the database.



Constraint Identification and Database Generation

- Sources of input for the AI process include:
  - Ship program specifications
  - Classification criteria
  - Various codes and standards
  - Design Practices
  - Physical model information

- With every ship and associated systems and machinery being different, a priority on defining constraints will improve operation and solution generation.

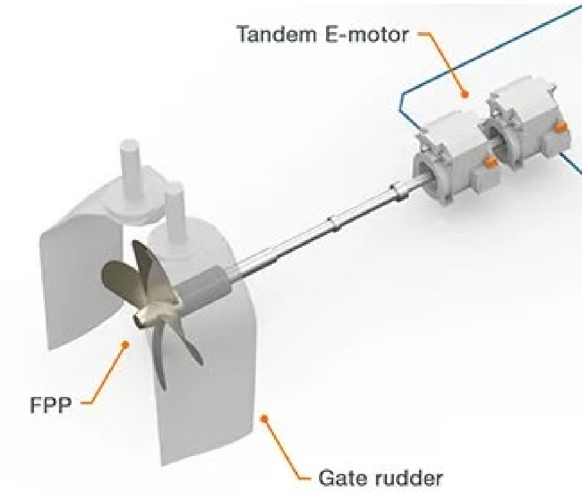


Spatial Constraints

- Spatial Constraints focus on the high-level physical limitations of the ship and machinery including:
  - Compartment dimensions and boundaries
  - Structural details within the Compartment
  - Unusable or reserved space
  - Unblockable areas or components (doors, hatches, intakes, uptakes, seachests, etc.)
  - Machinery information (weight, dimensions, center of gravity, etc.)

Tier 1 Equipment Performance Constraints

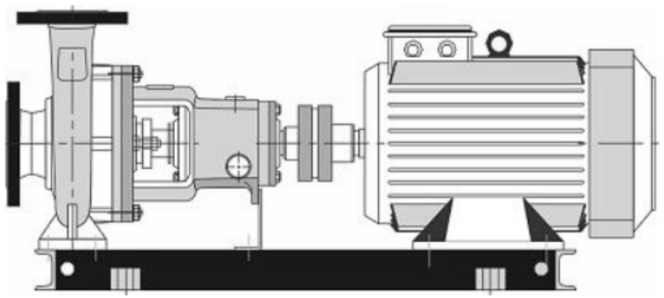
- Each piece of equipment has limitations, required services, identified consumers, and various other requirements.
  - For Tier 1 classified equipment, constraints are assigned dominance over other equipment due to priority for ship performance.
  - For the tandem Electric Propulsion Motors (EPMs), the criteria of alignment with shafting is a major dominant constraint limiting its placement in the compartment.



Item	Constraint
1	Overall Dimensions (L x W x H)
2	Overall Weight
3	Electrical Power Input and Source Location
4	Alignment with Shafting
5	Lubrication Criteria
6	Cooling Input Criteria
7	Cooling Outlet Criteria
8	Air Requirements
9	Drainage Outlet Criteria
10	Maintenance Envelope Dimensions and Locations
11	Ambient Space Requirements
12	Foundation Configuration

Tier 2/3 Equipment Performance Constraints

- Tier 3 piece of equipment, such as a centrifugal seawater pump, contains constraints that provide flexibility in arrangement.
- With few dominant constraints, pumps can be arranged more freely during the solution still with acknowledgement to performance effects due to:
  - Suction side distance
  - Elevation with respect to suction source and consumers.
  - Consumer routing
  - Pressure drops



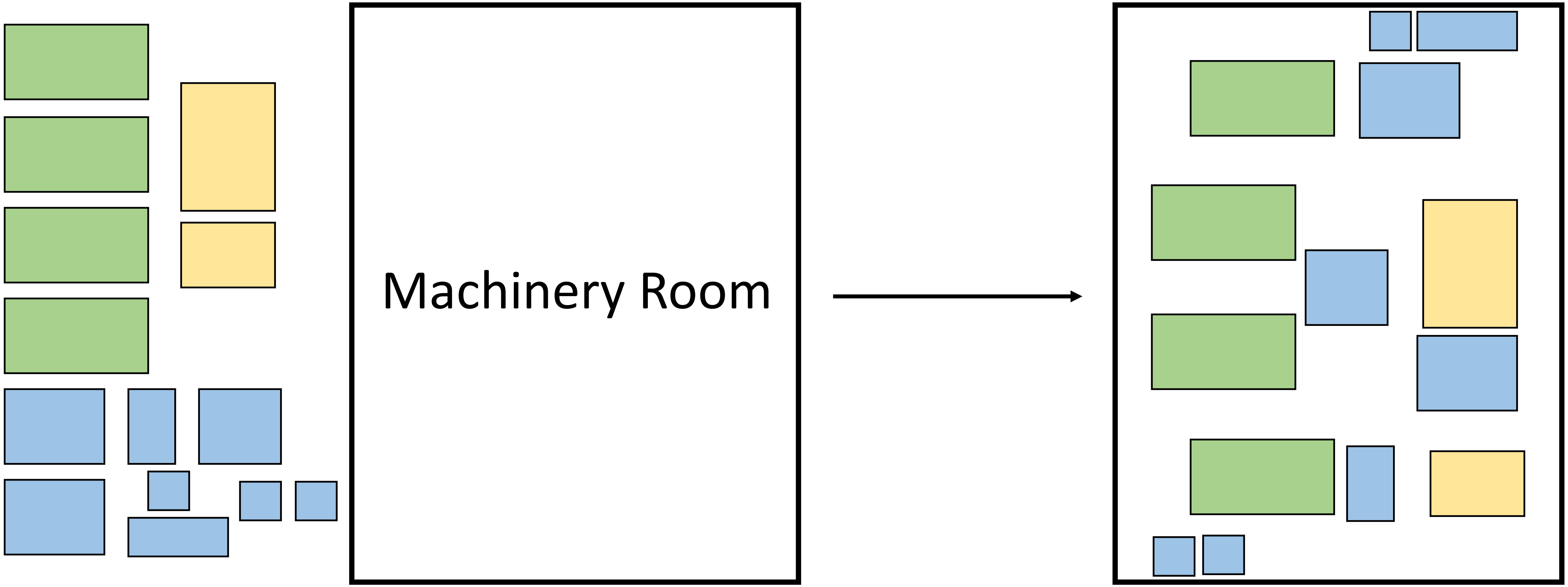
Item	Consumer Equipment
1	SSDG Heat Exchangers
2	Stern Tube Seal
3	Propulsion Motors
4	Thrust Bearing
5	Hydraulic Power Units
6	Chiller Plants
7	Refrigeration Units
8	Watermakers
9	Windlass Heat Exchanger

Item	Consumer Equipment
1	Overall Dimensions
2	Overall Weight
3	Component Orientation Requirements
4	Electrical Power Input and Source Location
5	Suction Pipe Length and Routing Criteria
6	Suction Inlet to Seachest Vertical Height
7	Consumer Locations and Pipe Routing Criteria
8	Drainage Outlet Criteria
9	Maintenance Envelope Dimensions and Locations
10	Skid Mounting Configuration

Maintenance, Human Engineering, Stability Constraints

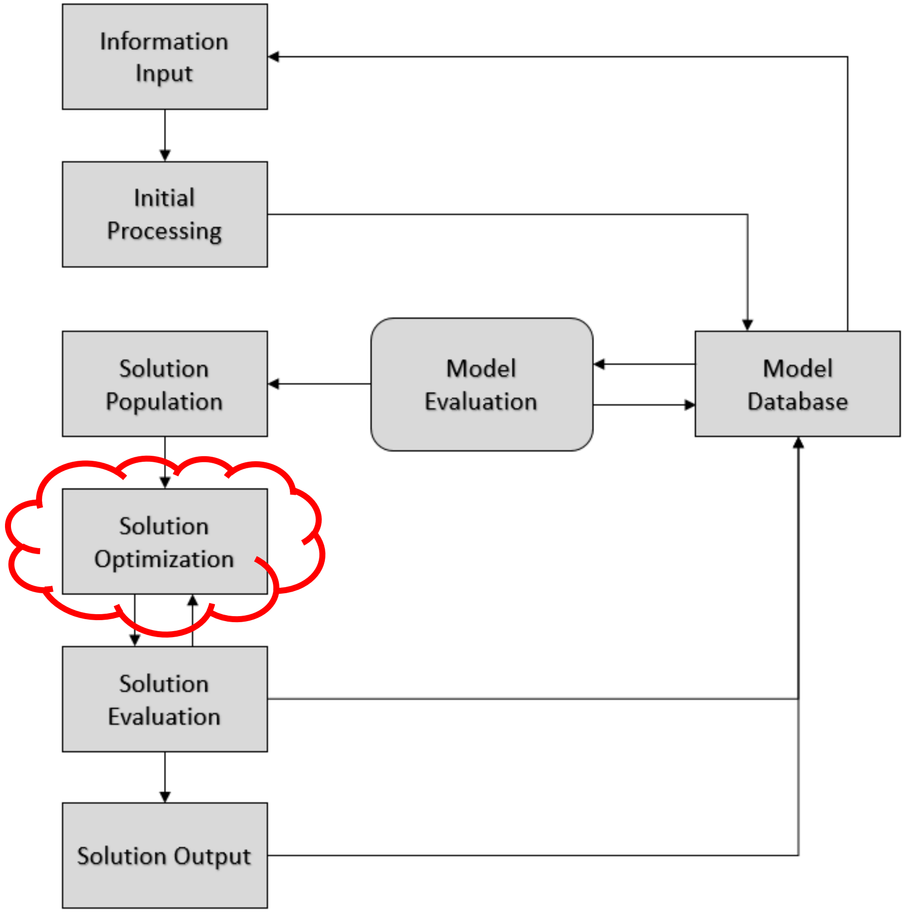
- Maintenance constraints mainly come in the form of spatial limitations from manufacturer requirements for access.
- Human engineering constraints from classifications, codes, standards, and ship specifications ensure:
  - Compliance
  - Workability
  - Controllability
  - Safe operation.
- Stability constraints mainly target high weight equipment to ensure arrangements consider overall ship performance and movement.

AI Machinery Arrangement Generation Goal



Existing or Parent Design Optimization

- In addition to utilizing the System for new Machinery Arrangement generation, other uses include improving or optimizing existing designs.
- Common instances where this is required:
  - Changes to parent design
  - Periodic optimization to almost finalized designs
  - Class design efforts when updating or improving



Arrangement Optimization

- Evaluation identifies Seawater pumps and Chilled Water pumps as a source of optimization.
  - Both pumps are not effectively located near source or consumers.
- System evaluates areas of system performance increase and weight reduction through:
  - Pump Net Positive Suction Head (NPSH) calculations.
  - System flowrate and pressure drop.
  - Required discharge pressure
  - Electrical/Motor Requirements
  - Routing inefficiencies and distances
- Solution outputted to switch arrangement locations of the Seawater and Chilled Water Pumps.

Arrangement Optimization Output

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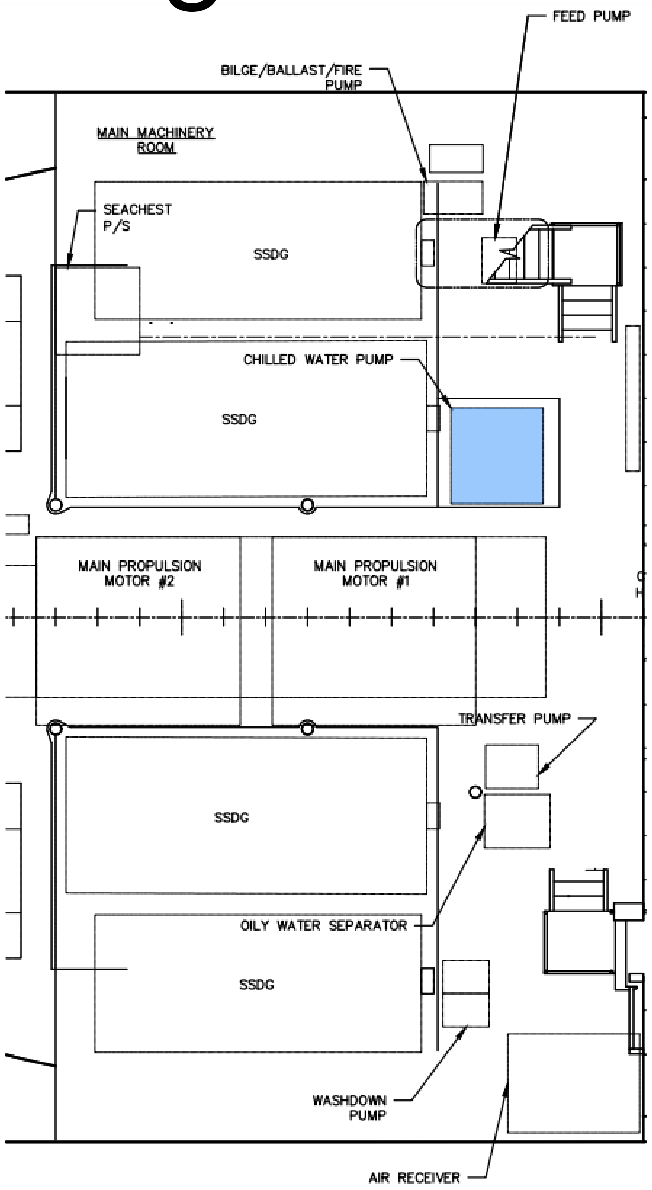
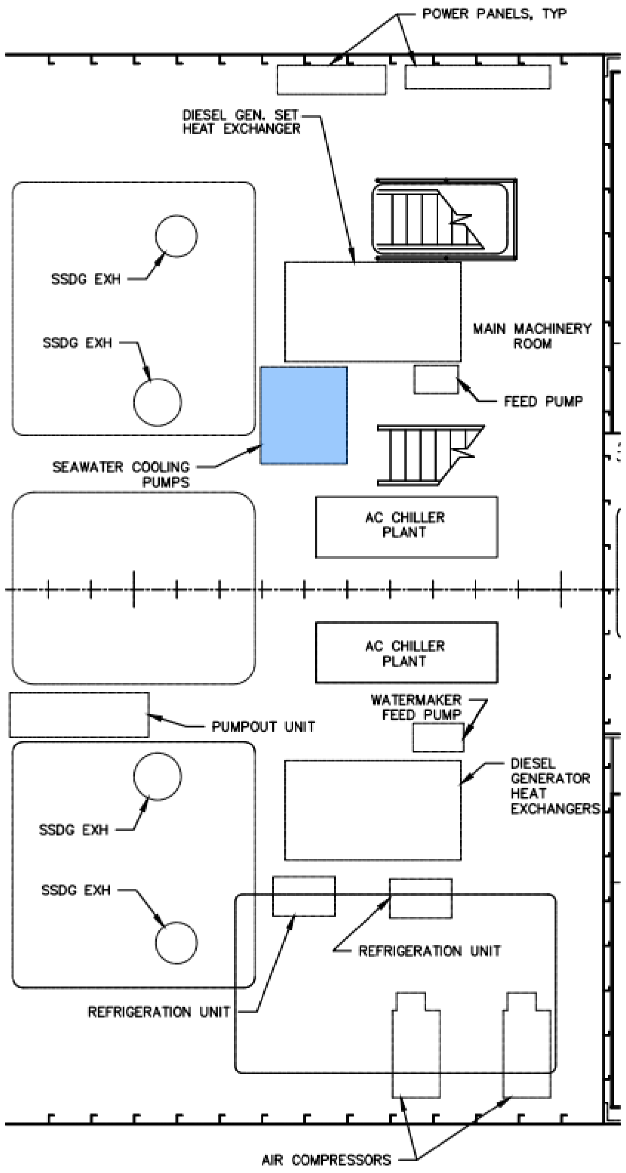
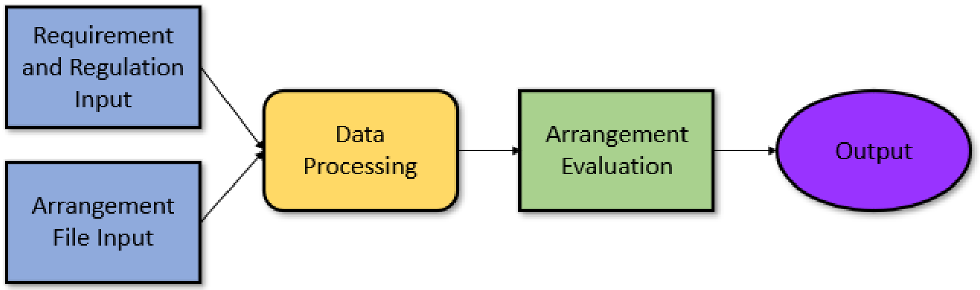


Mezzanine



Compliance Approval Feature

- With sourcing, processing, and utilizing specifications, standards, codes, and regulations, the AI driven system can additionally be used for final compliance checks.
  - Main application would be considering existing arrangements or parent designs due to the system incorporating compliance criteria when executing new machinery arrangement generation.
  - Arrangement files shall be inputted and processed with the corresponding regulations in question. Once evaluated, the system would provide notification of compliance or a list of failed criteria met.



Conclusions

- Evaluation offers substantial opportunity for reduced SWAP-C metrics and overall reduction of program schedule and labor hours.
- Complexity of ship design and machinery room arrangements leads to initial development comprising of simpler iteratives building up to this application.
  - Current technologies and processes sufficient for less complex problem of arranging equipment in a limited space.
  - High complexity of evaluating arrangement based on various, specific, and dynamic constraints and performance requires substantial development efforts.
- Key areas of applications being machinery arrangement generation, optimized design, and compliance verification, but also open to future expansion.

Further Discussion and Path Forward

- Important to acknowledge the usage or adaptation of current AI tools and systems currently in use rather than ground up development.
- Initial step for development would be ensuring system can input, process, and learn ship specifications, requirements, regulations, standards, etc. to be effective in the evaluation processes.
- Generation or optimization would begin with support from industry, such as Altair, to prioritize simpler "block" machinery arrangements with the goal to iteratively build in definition and complexity after testing success.
- As technology and systems develop, application could increase from machinery arrangements to full scale ship general arrangements.

Thank You for Your Attention