FLEXIBLE AND ADAPTABLE SHIP OPTIONS: ASSESSING THE FUTURE VALUE OF INCORPORATING FLEXIBLE SHIPS DESIGN FEATURES INTO NEW NAVY SHIP CONCEPTS

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Introduction

- Research Goal: Assess total future value of Flexible Ships design features to enable affordable war fighting relevance over a ship's full service life.
  - Affordable War Fighting means a higher cost now but greater ROI over the entire service life and lifecycle of the ship.
  - IRM methodology can be used to support and refine the Future Surface Combatant Analysis of Alternatives.
- Methodology provides a reusable, extensible, adaptable, and comprehensive advanced analytical modeling process.
- Will help the U.S. Navy in quantifying, modeling, valuing, and optimizing a set of ship design options.
- Results used to develop a robust business case for making strategic design decisions, under uncertainty.

The Five Tenets of Flexible Ships*

- Payloads Decoupled from Platforms
- Standard Interfaces
- Rapid Reconfiguration
- Planned Access Routes
- Allowance Margins for Modernization

*Directorate, Office of Science and Technology, NAVSEA

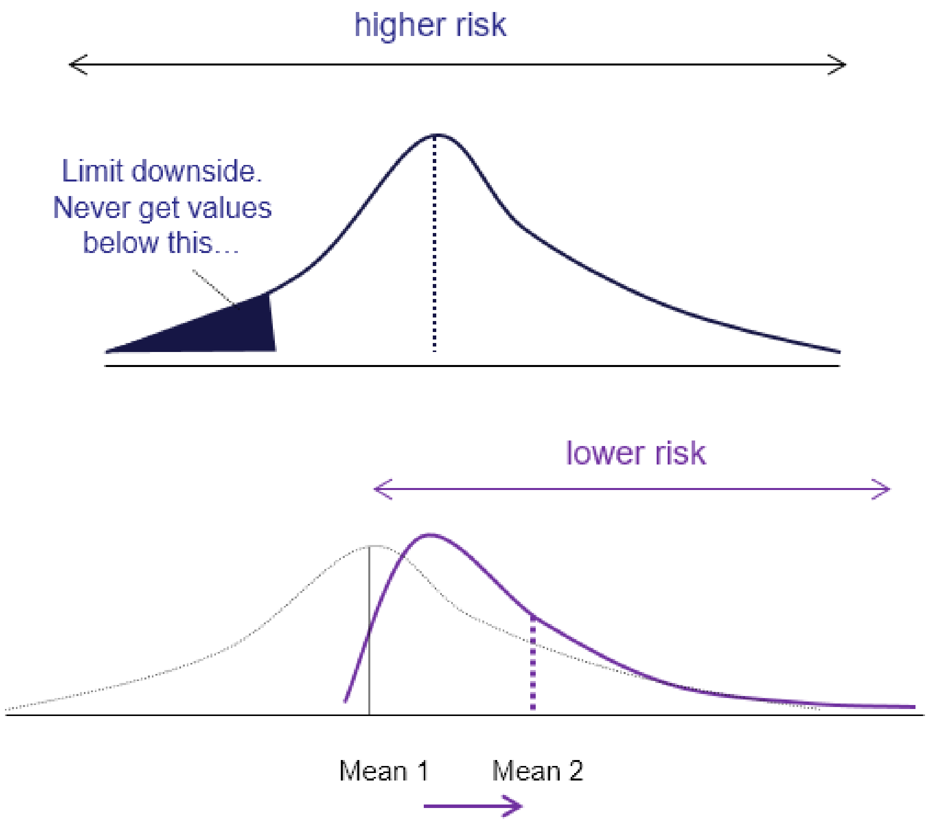
What are Real Options?

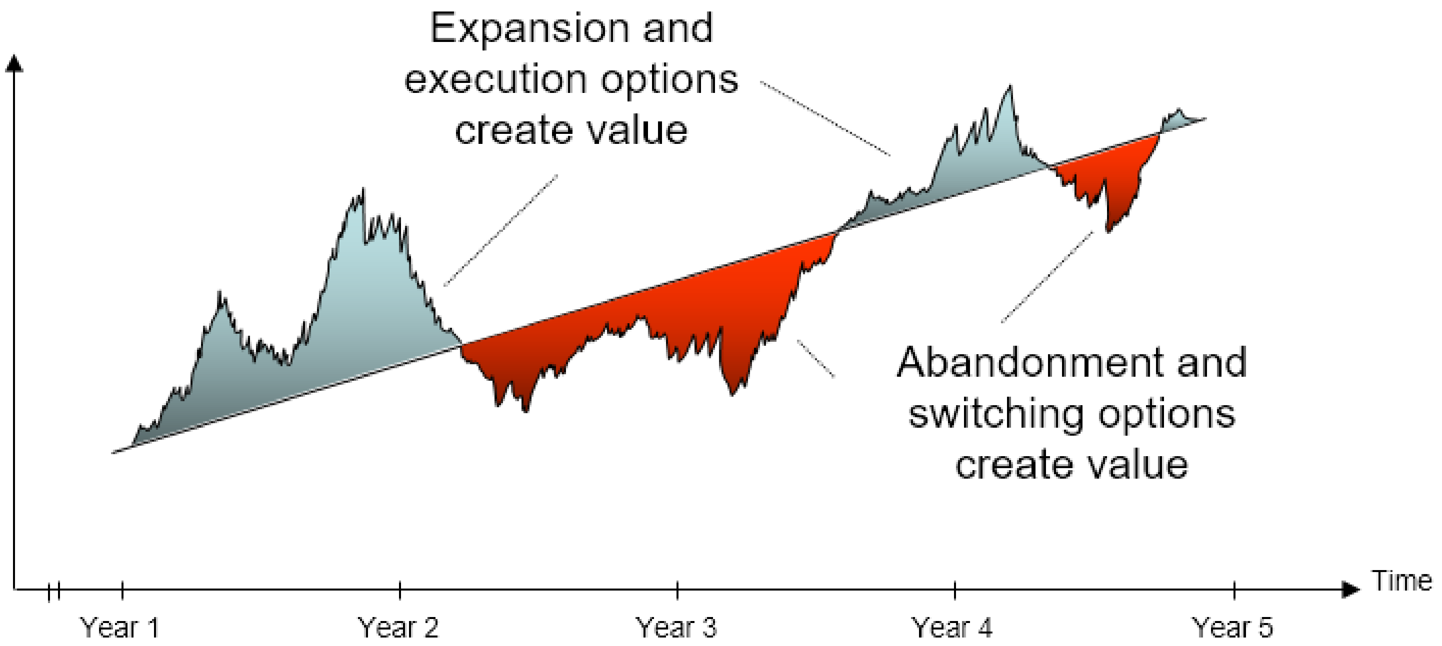
Traditional decision analysis approach:

- Provides single decision pathway
- Allows only one future outcome
- Locks in a single risk rate
- All assumptions determined at the outset

Real Options approach:

- Allows multiple decision pathways
- Maximizes financial flexibility
- Recognizes managerial decision making
- Incorporates new assumptions over time
- Allows variable risk


higher risk
Limit downside.
Never get values
below this…
lower risk
Mean 1
Mean 2


Expansion and
execution options
create value
Abandonment and
switching options
create value
Time
Year 1
Year 2
Year 3
Year 4
Year 5

Benefits of Flexible Ships* (I)

- Affordable warfighting relevance over the entire ship service life (higher cost now but greater ROI over the service life and lifecycle of the ship).
- Parallel development of payload vs. platform production (give me the power and space I need and we will bring in the weapon systems later, e.g., directed energy weapons).
- Reduction from lengthy and costly ship production work (make it easier up front for later swapping of technologies without predefining the exact point solutions of future unknown capabilities and timing).
- Increased competition and innovation (helps commoditize systems, without need to sunset).
- Cross platform commonality (LCS missions bay with the proper configuration management).

Benefits of Flexible Ships* (II)

- Rapid Prototyping of Payloads for rapid acquisition of new capabilities (growth margins and future growth potentials are prebuilt).
- Modular Open Systems increases acquisition agility (put the studs in and do the panels later as needed, whether it be ceramic, Kevlar, high intensity polymers).
- Standard Interfaces provide for common platforms and enclosures, swappable equipment.
- Efficient technology refresh, faster incremental upgrades, and faster development, faster technology adoption and fielding.
- Paces future threats (flexible in meeting unknown future threats, cost, schedule, capability).

The Challenge

- Flexibility vs. Affordability. Long term value, not immediate gains.
- Strategic Point of View. Flexibility means thinking through the future on where we might want the U.S. Navy to go.
- A Tactical Approach. With any upcoming repairs, implement small modularity capabilities instead of repairing back to the original.
- The next phase of the research looks at building business case models to justify flexibility. We need to consider the need to “cut steel” during major ship alterations vs. faster implementation. Also, the higher the number of deployments and ships on station we obtain with flexible ships (opportunity costs of not being active in the fleet, back on station faster, faster schedule and lower labor and ship alteration costs in the future).

Case Examples of Flexible Ships (I)

- AEGIS Ashore. Aegis with SPY-6 Radar where modularity was a result rather than being designed-in up front. The need was for reusability on ships with rapid setup and deployment as well as rapid take down of equipment. MDA working with the Navy and ACE. The relocatable requirement forced the need for modularity.
- Air Missile Defense Radar (AMDR) SPY-6 architecture has enhanced capabilities including longer range and greater number of issues detection, a game changer. The main advancement is its longer range and ability in simultaneous threat assessments, and is integrated with the AEGIS system. AMDR is sensor agnostic with an open architecture, solid state system, and standard interface. Additional data links can be added quickly and cheaply, with simple maintenance and higher efficiency. Can also be integrated with other Electronic Warfare (EW) systems for rapid kill assessments and coordination of soft kill and hard kills.

Case Examples of Flexible Ships (II)

- Directed Energy Weapons
  - A lot of unknowns such as power density needs (watts/cm), aperture physics, capability of continuous tracking and targeting high speed objects, and other advanced threats (e.g., Hyperglides, UAV swarms).
  - The idea is to have excess and on-demand power (you have it the instant you need it, and to have more than you will need).
- Hybrid Power Systems and Storage for Directed Energy Weapons
  - Leverage 30X sensor improvement with only 2X power needs.
  - Constraints are the ship's size, weight, cooling, and fire control.
  - Need capabilities to face unknown future advanced threats. Capability gaps are identified with the help and coordination of the intelligence community.
  - The idea is not to have a perfect single point estimate foresight of capability needs but to be prepared to implement a range of future unknown systems to meet a set of future unknown threats.

Case Examples of Flexible Ships (III)

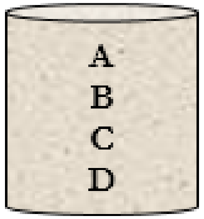
- High Density Power
  - DDG51 FLT III presents an opportunity to upgrade its power plant for FY2020 to accommodate directed energy weapons (sponsor buy-in and the budget requirement to make sure things get into production on time… clock starts now).
  - Requires fast charge and ready at a moment's notice and instantaneous requirements. Power and energy is the foundation of the kill chain.
  - The uncertainty is that there is a stochastic load demand, which means that if the Navy is using directed energy weapons, they'd better have plenty of it.
  - With a capability to handle large demand loads, advanced solid state circuit protection and robust combat power controls are also required.
  - There needs to be a multifunction energy storage capability with a compact power conversion structure to reduce size and weight.
  - Unknowns: AC vs. DC, 6/12/18 KV system, heat loads and coolant levels, outputs (4MW x 20 buses) for Medium Volt DC, frequency, power conversion, storage area, fit on smaller ships, decoupled buses and needs for rotor alignments…

Case Examples of Flexible Ships (IV)

- CANES Backfit
  - Started in 2013. Expectation that all surface combatants (~180) would be fully operational by 2022.
  - CANES undergoes a software refresh every two years and hardware upgrades every four years.
  - Given the extra volume that was built into LPD-17 (margin for growth and easier accessibility – wider main peeway to accommodate larger item) the CANES backfit (replacing SWAN) on LPD-17 been more cost efficient than the CANES backfit on the DDG Flight IIA.
- LCS Missile Module
  - Initial module was funded by the Army for the XM501 NLOS Launch System.
  - The program was canceled in 2010 and the Navy was left without a replacement. Because the LCS was designed for a modular missile payload instead of being designed with a structurally integral missile system, the LCS was able to deploy and meet mission requirements while a new modular missile payload was developed.
  - The Hellfire Longbow was structurally tested in 2017 on USS Detroit.
  - This example highlights the cost savings of modularity. If LCS has been structurally designed with the XM501, replacement would have been costly, with extended yard periods and the ship would not have been able to deploy. With the modular missile bay, LCS was able to deploy while parallel development of a new missile module took place.

1 QUALITATIVE MANAGEMENT SCREENING

RISK IDENTIFICATION

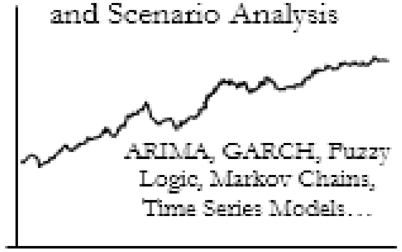


Start with a list of projects or strategies to be evaluated that have already been through qualitative screening…

2 FORECAST PREDICTION MODELING

RISK PREDICTION

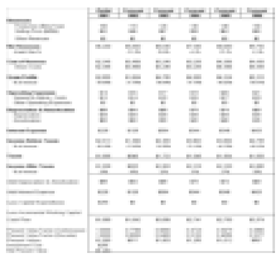
Back-fitting, Forecasting and Scenario Analysis



…with the assistance of forecasting algorithms, future outcomes can be predicted...

3 BASE CASE STATIC MODELS

RISK MODELING



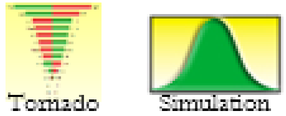
Traditional analysis stops here!

…create traditional static base case financial or economic models for each project…

4 DYNAMIC MONTE CARLO RISK SIMULATION

RISK ANALYSIS

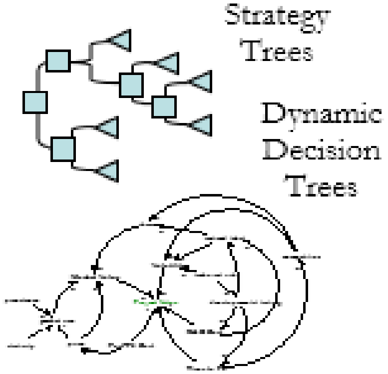
Simulate thousands of scenario outcomes



…Tornado analysis identifies critical success factors, then dynamic sensitivities and Monte Carlo risk simulations are run…

5 REAL OPTIONS PROBLEM FRAMING

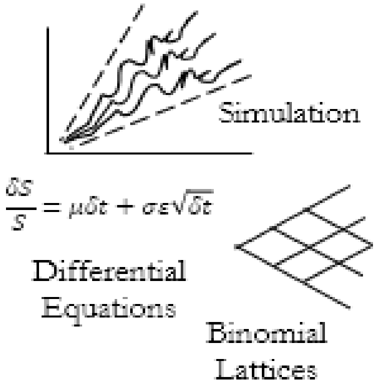
RISK MITIGATION



…strategic real options are framed to hedge and mitigate downside risks and take advantage of upside potential…

6 REAL OPTIONS VALUATION AND MODELING

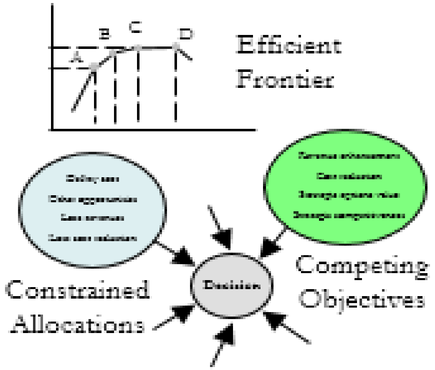
RISK HEDGING



…the real options are valued using binomial lattices and closed-form partial-differential models with simulation…

7 PORTFOLIO AND RESOURCE OPTIMIZATION

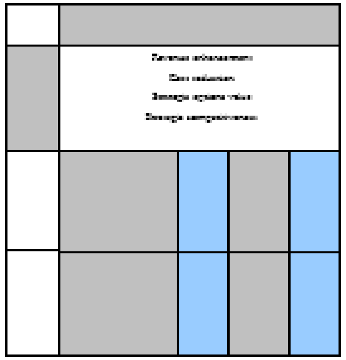
RISK DIVERSIFICATION



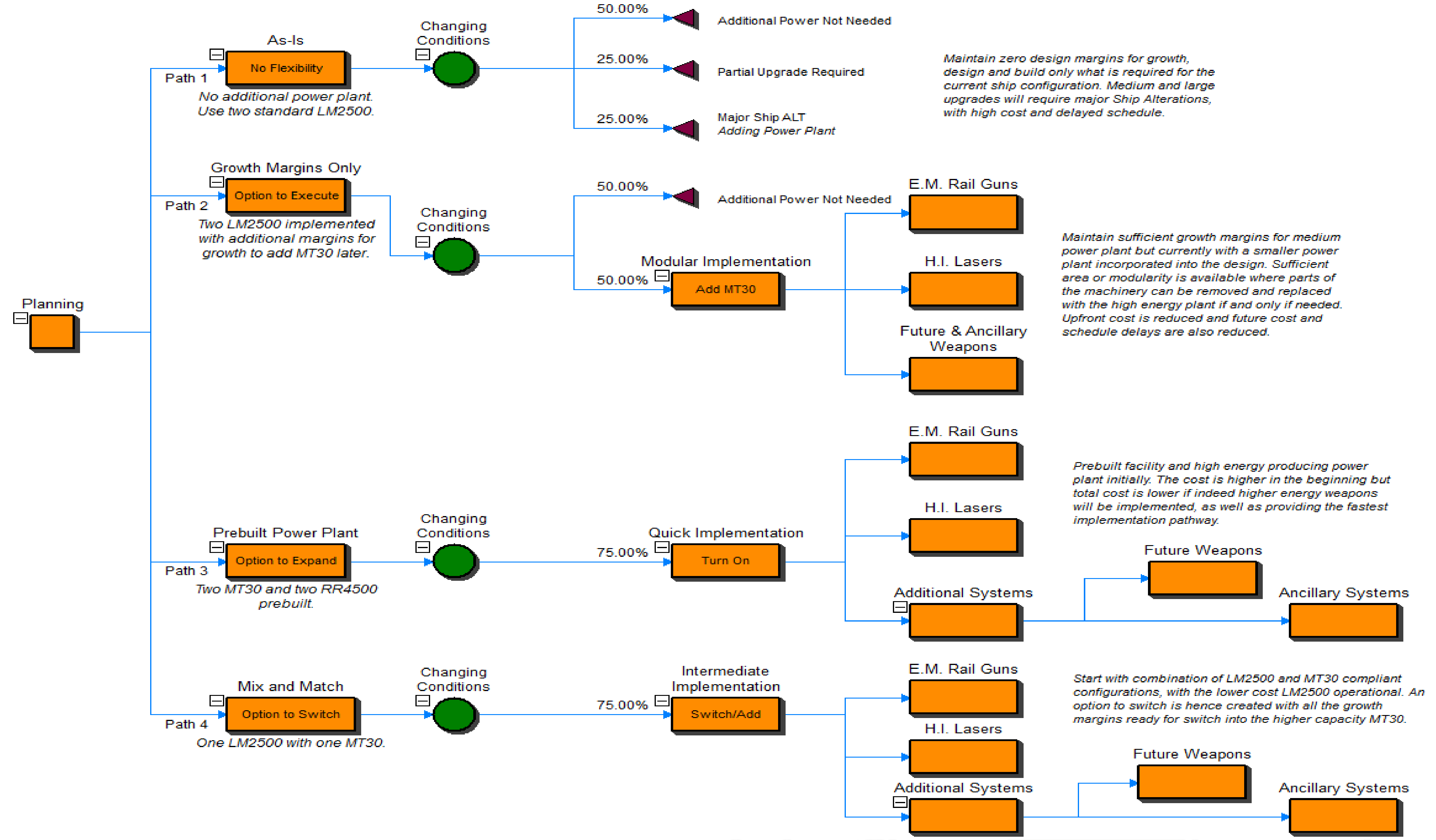
…stochastic optimization on multiple projects for efficient asset allocation subject to resource constraints…

8 REPORTS, PRESENTATION, AND UPDATES

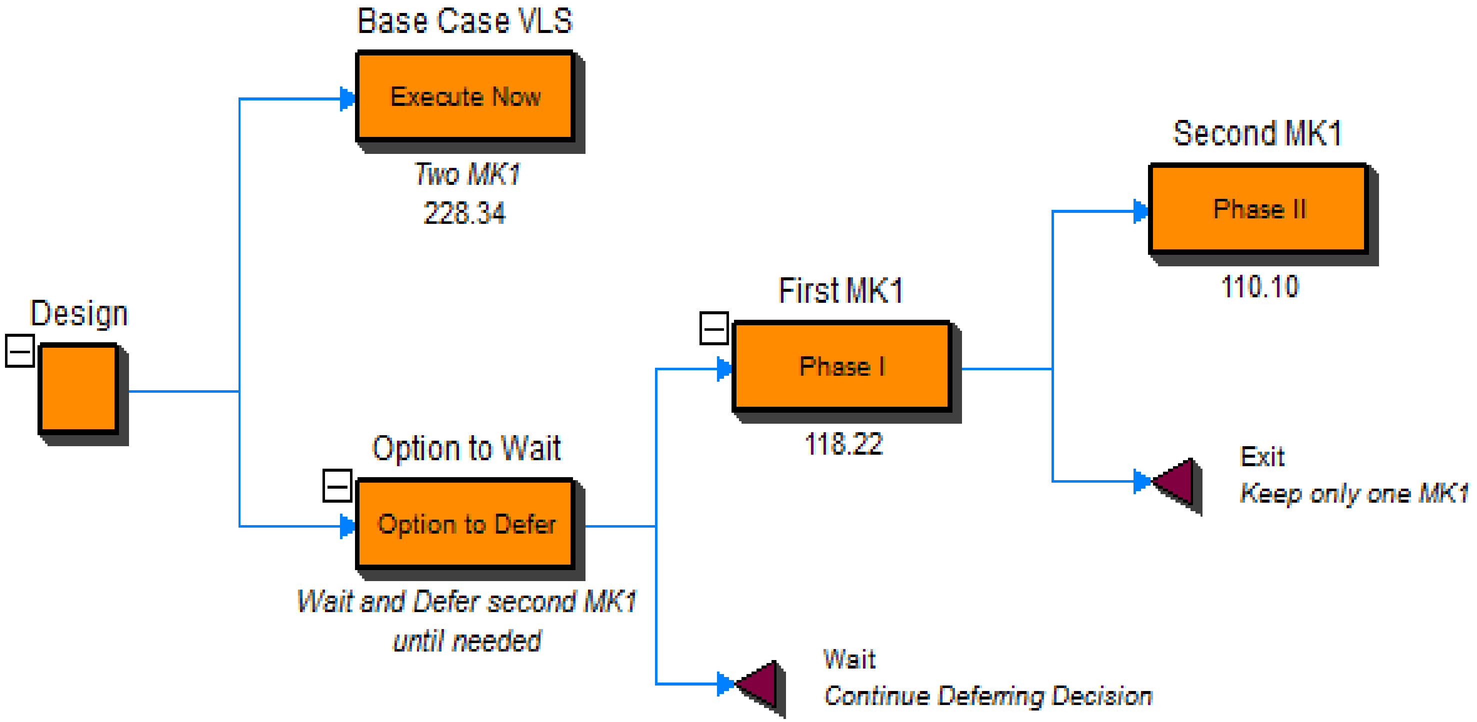
RISK MANAGEMENT



…create reports, make decisions, and update analysis iteratively when uncertainty is resolved over time…



Planning
As-Is
No Flexibility
Path 1
No additional power plant.
Use two standard LM2500.
Changing Conditions
50.00%
Additional Power Not Needed
25.00%
Partial Upgrade Required
25.00%
Major Ship ALT
Adding Power Plant
Maintain zero design margins for growth, design and build only what is required for the current ship configuration. Medium and large upgrades will require major Ship Alterations, with high cost and delayed schedule.
Growth Margins Only
Option to Execute
Path 2
Two LM2500 implemented with additional margins for growth to add MT30 later.
Changing Conditions
50.00%
Additional Power Not Needed
Modular Implementation
50.00%
Add MT30
E.M. Rail Guns
H.I. Lasers
Future & Ancillary Weapons
Maintain sufficient growth margins for medium power plant but currently with a smaller power plant incorporated into the design. Sufficient area or modularity is available where parts of the machinery can be removed and replaced with the high energy plant if and only if needed. Upfront cost is reduced and future cost and schedule delays are also reduced.
Prebuilt Power Plant
Option to Expand
Path 3
Two MT30 and two RR4500 prebuilt.
Changing Conditions
75.00%
Quick Implementation
Turn On
E.M. Rail Guns
H.I. Lasers
Additional Systems
Future Weapons
Ancillary Systems
Prebuilt facility and high energy producing power plant initially. The cost is higher in the beginning but total cost is lower if indeed higher energy weapons will be implemented, as well as providing the fastest implementation pathway.
Mix and Match
Option to Switch
Path 4
One LM2500 with one MT30.
Changing Conditions
75.00%
Intermediate Implementation
Switch/Add
E.M. Rail Guns
H.I. Lasers
Additional Systems
Future Weapons
Ancillary Systems
Start with combination of LM2500 and MT30 compliant configurations, with the lower cost LM2500 operational. An option to switch is hence created with all the growth margins ready for switch into the higher capacity MT30.


Base Case VLS
Execute Now
Two MK1
228.34
Design
Option to Wait
Option to Defer
Wait and Defer second MK1
until needed
First MK1
Phase I
118.22
Second MK1
Phase II
110.10
Exit
Keep only one MK1
Wait
Continue Deferring Decision

Yeah, there's some math involved…

For instance, we first start by solving for the critical value of I, an iterative component in the model using:

$$X_2 = Ie^{-q(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q+\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right)$$
$$-X_1e^{-r(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q-\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right)$$

Then, solve recursively for the value I above and input it into the

$$Compound\ Option = Se^{-qT_2}\Omega\left[\frac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}};\ \frac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}};\ \sqrt{t_1/T_2}\right]$$
$$-X_1e^{-rT_2}\Omega\left[\frac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}}-\sigma\sqrt{T_2};\ \frac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1};\ \sqrt{t_1/T_2}\right]$$
$$-X_2e^{-rt_1}\Phi\left[\frac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1}\right]$$

The preceding closed-form differential equation models are then verified using the risk-neutral market-replicating portfolio approach assuming a sequential compound option. In solving the market-replicating approach, we use the following functional forms (Mun, 2006):

- Hedge ratio *(h)*:

  $$h_{i-1} = \frac{C_{up}-C_{down}}{S_{up}-S_{down}}$$

- Debt load *(D)*:

  $$D_{i-1} = S_i(h_{i-1}) - C_i$$

- Call value *(C)* at node i:

  $$C_i = S_i(h_i) - D_i e^{-rf(\delta t)}$$

- Risk-adjusted probability *(q)*:

  $$q_i = \frac{S_{i-1}-S_{down}}{S_{up}-S_{down}}$$ obtained assuming

  $$S_{i-1} = q_i S_{up} + (1-q_i)S_{down}$$

- This means that

  $$S_{i-1} = q_i S_{up} + S_{down} - q_i S_{down}$$ and $$q_i[S_{up}-S_{down}] = S_{i-1}-S_{down}$$,

  so we get $$q_i = \frac{S_{i-1}-S_{down}}{S_{up}-S_{down}}$$