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Integrating Cost Estimating with the Ship Design Process

ABSTRACT

The ship design process is an evolutionary process where at the conceptual design level, pre Milestone A for Naval acquisition programs, few details are know and the metrics used for estimating costs are based on analogous platforms and limited parametric functions. As the design process continues towards Milestone B the design begins to take shape with fewer analogies and an increasing number of parametric cost drivers. At this point, 80% of the life cycle costs (LCC) are set and the cost risk associated with the design becomes an important piece of the overall acquisition costs. It is imperative that the methods used to estimate the cost and cost risk are tightly coupled with the design iteration process and are parametric in nature in order to support the needs of the Program Manager in terms of not only the basic design but design trade-offs.

The authors present the use and benefits of employing a set of parametric cost models during the concept and preliminary phases of ship design. These cost models produce quick assessments of costs and risk, for design and mission trade-off alternatives. The cost models, being parametric, can follow the evolutionary design process. At early stages of the design, when many details of the design are not yet available, the cost models automatically provide statistically-synthesized values for missing parameters. Then, as the design matures, these default values can be replaced with values developed for the design.

INTRODUCTION

The cost models provide a range of structural, powering and manning selections to predict weights, costs and various performance characteristics. The cost models substitute default ship design parameters, developed from statistical data analyses, until actual design data can be determined. In this way, the cost estimate can follow the design evolution and can quickly produce cost changes due to design trade off alternatives. Since the models are parametric, this allows many different design variables to be modified and the impact of these changes measured directly for cost and cost risk. Similar parameters apply to life cycle elements including the impact of crew, fuel price, and speed.

Separate baseline models are used for different hull types (Mono-Hulls, Catamarans and Trimarans). In addition, the baseline models have been extended to focus on particular ship types: for example, various high speed vessels, tankers, bulk carriers, container ships, patrol boats, cutters, frigates, hydro-graphics vessels, RO-CON-PAX ships, etc.

These cost models have been successfully used to estimate costs across a wide range of projects both military and commercial. The following are only a selection of projects where the cost models have been used.

- Navy Heavy Air Lift Seabasing Ship (HALSS): CCDoT cost estimates & risk assessments for building large trimaran under two different design & build strategies (traditional & virtual shipbuilding).
- Short Sea Shipping Trailership (SSST): CCDoT cost estimates for concept trimaran design for commercial and military modes, including preliminary returns on investment estimates.

- American Marine Highways High Speed Trimaran Dual-Use TrailerShip: CCDoT design, construction and life cycle cost estimates to estimate cost of naval defense features and commercial return on investment (ROI).
- Navy High Speed Sealift Navy Vision Trimaran (HSS): NSWCCD cost estimates for high speed composite sealift concept ship.
- Cost estimates for commercial SWATH & SLICE ferries & crew/supply boats
- Navy Joint High Speed Vessel (JHSV) Concept Trimaran: Cost estimates for baseline design plus three military variants.
- Navy Joint High Speed Vessel (JHSV) Concept Catamaran: Cost estimates for baseline design plus two military variants.
- USCG FRP-B Fast Response Patrol Boat (Steel, Aluminum & Composite Variants) with alternate build strategies
- USCG NSC National Security Cutter for five alternate build strategies
- Foreign-built Naval Hydrographic/Anti-Mine Warfare Ship: Cost estimates for three (3) size ships built under two different design & build strategies.
- Foreign-built frigate cost estimates
- Cost estimate for concept naval corvette: Estimating cost and schedule savings potential from advanced design and construction methods with modularized equipment and outfit components.

HOW THE COST MODELS WORK

The following describes the general characteristics of how the cost models work.

Parametric Cost Data

The cost models are parametric and offer a wide range of options: dimensional; cargo carrying capacity; propulsion systems; crew and passenger size; structural materials, systems and equipment.

The Cost Estimating Relationships (CERs) represent a wide cross-section of current and historical shipyard construction costs at many levels of detail. They reflect how ships are built.

The CERs primarily are not weight-based, but based on many different metrics: for example, crew size, power kW, compartment volume, etc., etc. These CERs were developed from a comprehensive data library residing on SPAR's estimating system called *PERCEPTION ESTI-MATE.* These CERs, while parametric in nature, focus on a specific area of cost: systems, subsystems, components and modules. Each reflects the specific material and the manufacturing and assembly processes required.

The CERs used in the cost models are based on average costs that are expected from a mid-sized U.S. commercial shipbuilder. These CERs are referred to as the "generic" CERS. In order to compile generic CERs for the cost models, adjustments have been made for different shipyard productivities, manufacturing and construction methods and material costs. The cost models provide features for applying various productivity factors to these CERs to accommodate average cost differences between commercial and military shipbuilding business practices as well as for other non-generic considerations discussed below.

The cost model's approach for an estimate is based first upon the composition of the hull's structural components (decks, bulkheads, shell, double bottoms, superstructure, etc.). Each block type carries a different CER, mostly for labor, since each requires a different set of manufacturing, assembly and erection processes; therefore each type has its own cost on a per ton basis. However, structural materials also can vary from component to component, such as high strength steel for high stress areas or armor protection, light aluminum or composite materials for superstructures, etc. The CERs address these differing requirements. For applications where the structural definition is less detailed, the cost models use more global CERs based mostly on similar hull forms, such as typical high speed mono-hulls, high-speed catamarans, etc. However, estimators also can apply their own judgment factors to these CERs in order to address non-typical differences that might be apparent in the specific design at hand.

The cost models then focus on the user-defined ship systems (mechanical, piping, electrical, HVAC, etc.) and upon other ship dimensional and performance characteristics.

Details of the estimate are generated at approximately the 3-digit level of the Ship Work Breakdown Structure (SWBS).

Estimate Calculations

The cost models generate estimates using the following general calculations for labor and material cost and price:

Labor Hours, Cost & Price

$$\text{Labor Hours} = QTY_{UOM} \times CER_{Labor} \times Factor_{Usage} \times Factor_{Productivity} \quad [1]$$

Where,
QTY_{UOM} = Quantity of the unit of measure used for developing the labor cost
CER_{Labor} = Labor Hour CER per unit of measure
$Factor_{Usage}$ = Usage factor that may increase/decrease the value of the CER
$Factor_{Productivity}$ = Labor productivity Factor

$$\text{Labor Direct Cost} = \text{Labor Hours} \times \text{Labor Rate}_{\$/Hour} \quad [2]$$

Where, Labor Rate $_{\$/Hour}$ = Unburdened dollars per hour

$$\text{Labor Indirect Cost} = \text{Labor Direct Cost} \times \text{Rate}_{\%\ Overhead} \quad [3]$$

Where, Rate $_{\%\ Overhead}$ = Percentage overhead applied to direct labor cost

$$\text{Total Labor} = [\text{Labor Direct Cost} + \text{Labor Indirect Cost}] \times [1 + \%\text{Profit}] \quad [4]$$

Where, %Profit = the percent profit applied to total cost

Material Cost & Price

$$\text{Material Direct Cost} = QTY_{UOM} \times CER_{Material} \times Factor_{Material} \times Factor_{Usage} \quad [5]$$

Where,
$CER_{Material}$ = Material CER per unit of measure
$Factor_{Material}$ = Material cost factor

$$\text{Material Indirect Cost} = \text{Material Direct Cost} \times \text{Rate}_{\%\ Material\ G\&A} \quad [6]$$

Where, Rate $_{\%\text{ Material G\&A}}$ = Percentage of general administrative costs, if applicable, to be applied to direct material cost

Total Material = [Material Direct Cost + Material Indirect Cost] x [1 + %Profit] [7]

Productivity Factors

The cost models provide features for applying productivity factors for both design and construction to suit anticipated contractor performance; the type of shipyard and its established product line; its facilities and production capabilities; and the expected effectiveness of the shipyard to plan and manage its resources, costs and schedules.

When estimating cost, there are a number of issues that need to be considered.

The models are sensitive to the cost impact of the build strategy and allow cost comparisons for different approaches. Factors that need to be considered are the anticipated extent of on unit, on block and on board construction and the relative density of on-board outfit.

While there is a concept of a standard cost for performing a specific element of work, the actual cost will always vary depending who, when and where the work is to be performed. A shipyard that has the right equipment and facilities, a skilled work force, a competent plan and management team will almost always perform the work more quickly and less expensively than the shipyard that is compromised in one or more of these areas. In addition, a standard cost may identify expected costs for work under "normal" circumstances, but the actual cost will likely be higher if the work area is congested, confined and/or difficult to reach.

There are other technical issues that need to be considered. Working to a poorly engineered design will always be more costly than working to one that is well done and easier to build. An extension to this is whether or not technical information is readily available when the work is scheduled to begin. For example, if technical information is not available at early stages of construction, when work can be performed more efficiently, the work will need to be scheduled later in time when efficiency is less likely, often by cost factors of 3-5 times. Such savings from early stage construction is the objective for on-unit and on-block outfitting versus on-board outfitting when work carries a much higher burden of lost productivity.

Therefore, for a cost estimate to be realistic the following issues need to be considered and their effects included:

1. Available & capable facilities
2. Experienced & skillful work force
3. Good planning & early stage outfit scheduling
4. Experienced and competent management
5. Efficient business practices
6. Quality design and engineering
7. Minimum change orders

It is assumed that rework is not included in a cost estimate except as a consideration for cost risk. Owner changes can impact costs too, but they should be covered with a set aside estimate line item or decided later as a subsequent renegotiation of the scope of work.

All of the above issues influence the relative level of productivity for the shipbuilder working on a given contract.

The cost models provide for several types of productivity factors.

1. For technical support
2. For structural manufacturing and assembly work
3. For outfit manufacturing and assembly work
4. For material costs

For the notional shipyard for which the generic CERs apply, each of the above productivity factors equal 1.00. For more productive shipyards, the factors are less than 1.00. For a less productive shipyard, the factors increase to values greater than 1.00**.**

As prime contractor for the U.S. Navy's Product Oriented Design and Construction ("PODAC") Cost Model in the late 1990s, SPAR researched relative productivities of a number of U.S. shipyards. Its findings are summarized in Figure 1. The study also compared data from various commercial shipyards and from data collected from several projects involving Northern European shipyards. Additional productivity factors were compiled and reported by Koenig, Narita and Baba, 2003 for East Asia.

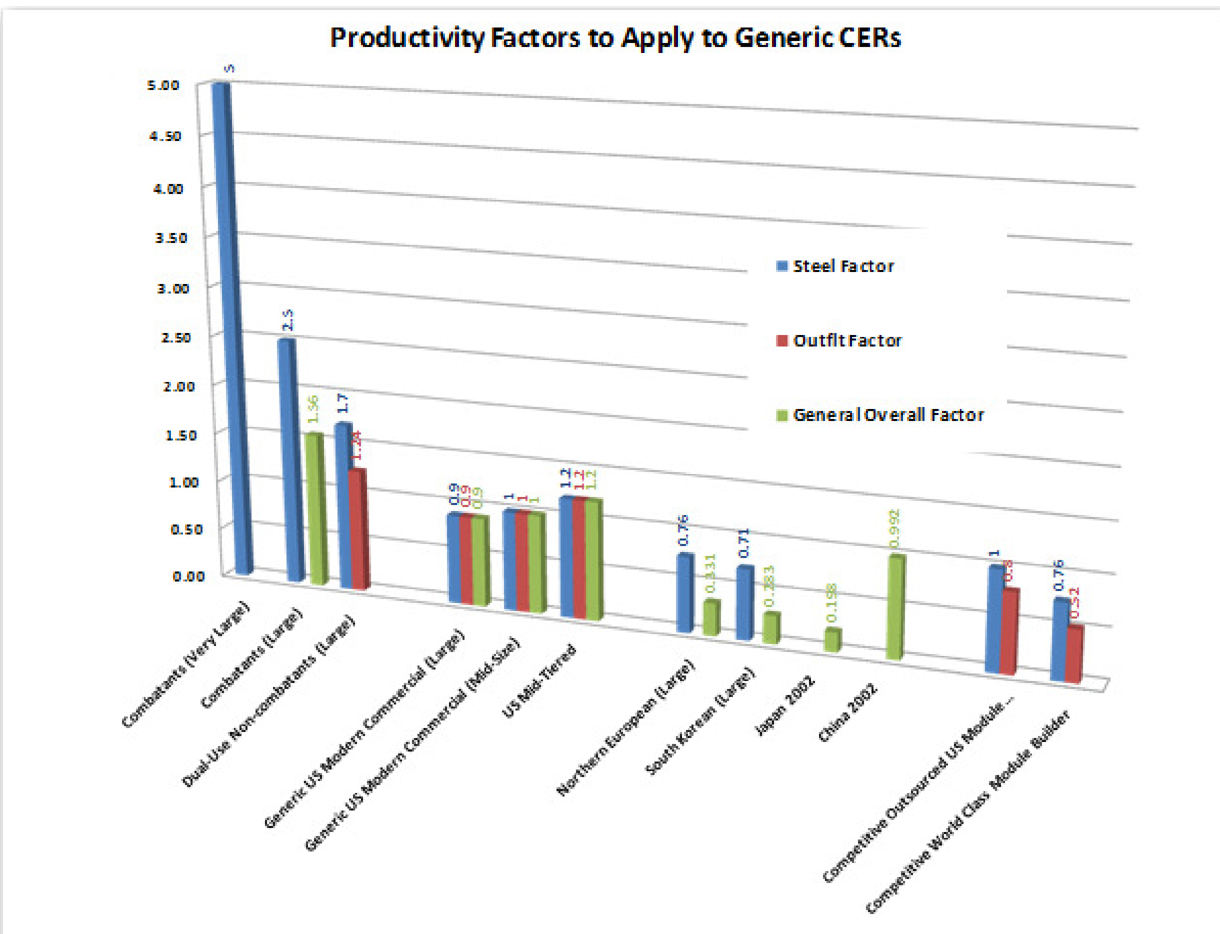

Figure 1: Relative Labor Productivity Factors

Outfit Density Factor

Recently, there have been documented assertions that one reason why naval ships have become so much more expensive to build is that they have become more complex and the density of outfit materials (SWBS Groups 200-700) in relatively confined spaces has driven up labor costs. Ship spaces that have high density outfit are more difficult to access and execute onboard work, hence higher construction labor cost.

However, as more work is being performed on-shore (on unit, on assembly, on block, etc.) the impact of higher space density on labor cost should become less of a problem.

Nevertheless, the cost models attempt to quantify these effects. It should be recognized that the method used by the cost models should not be considered accurate portrayals of how outfit density directly affects labor construction costs. There are considerable discrepancies in the data obtained from various sources, and the results used within the cost models may only point to a likely direction.

From a selection of ships, commercial and naval, the following density metric was developed:

$$\text{Density} = \sum(\text{SWBS 200-700 MTON weights})/\text{Ship } M^3 \text{ Displacement.} \qquad [8]$$

It attempts to measure outfit density (metric tons) within the confines of the ship envelop as measured by the ship displacement (cubic meters). Clearly, this is a very simplistic approach as it makes no adjustments for large volumes of essentially empty cargo spaces and large tank spaces, nor does it offer any granularity of density that may be more evident in particular areas of the ship such as the machinery spaces. Other short-comings are the following:

1. No adjustments made to labor hours due to differences in shipbuilding technology (par ex., pre-outfitted hull blocks, zone outfit, and bulk manufacturing)
2. No adjustments made to added labor hours for possible unstable or inadequate design that impacts upon production
3. No adjustments made to labor hours for differences in production costs, military versus commercial practices
4. No adjustments made to outfit weight (SWBS Groups 200-700) due to possible lighter weight systems or systems involving higher levels of technical sophistication.
5. No adjustments made for differences in type of system materials that otherwise affect labor hour.
6. No adjustments made for outsourcing selected outfit work that otherwise would be accounted for not as labor cost, but as material.

Figure 2 presents a statistical relationship for a density productivity factor that is a function of the ratio of total outfit (SWBS 200-700) weight to full load displacement (cubic meters). The generic CERs apply to more open area ship designs such as tankers and bulk carriers where their outfit density productivity factors are approximately 1.0. More complex ship types with greater densities of outfit exhibit higher density productivity factors.

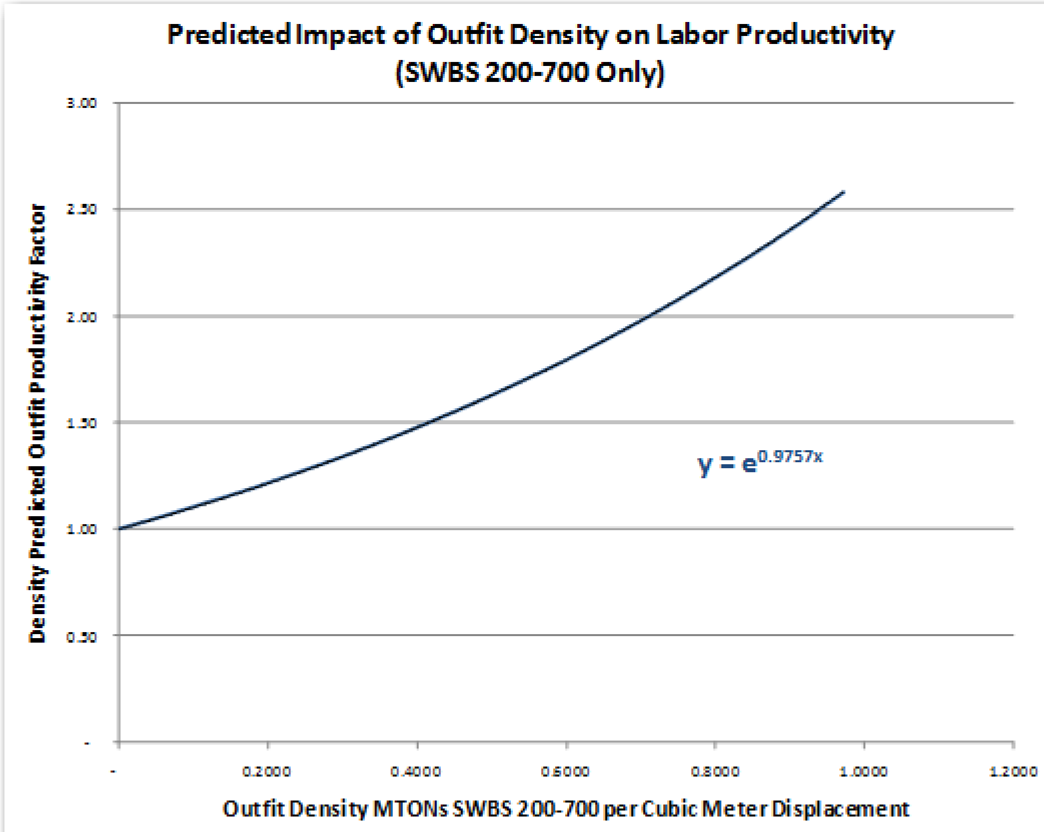

Figure 2: Cost Multiplier to Outfit Labor Hours per MTON versus Density

Material Cost Factor

Material costs also can vary, depending on the type of contract (Table 1). Mil-Spec materials are generally regarded as being of higher standards, such as for added shock protection. More significantly, vendors and suppliers will increase their prices to cover their added costs to provide the usually required military MIL-SPEC documentation on their products. Foreign shipbuilders often enjoy lower material prices due to greater backlogs and higher levels of purchasing power.

Combatants (Large)	1.210
Dual-Use Non-combatants (Large)	1.140
Generic US Modern Commercial (Large)	1.000
Generic US Modern Commercial (Mid-Size)	1.000
US Mid-Tiered	1.000
Northern European (Large)	0.850
South Korean (Large)	0.720

Table 1: Examples of Differences in Material Costs between Types of Shipbuilders

Commodity Based Material Cost Escalation

The cost model summarizes material costs and escalates them to a common or base year value defined by the user. The cost models assume that a contract will provide an escalation clause that reimburses the shipbuilder for cost increases expected for contract years beyond the base year.

Figure 3 tracks average U.S. shipbuilding material costs by major commodity index category, and estimates (forecasts) their changes for the foreseeable future. There is no reliable method available to forecast future year escalation and exchange rates. Forecasts are especially difficult to make during volatile economic and political conditions as they are today.

These indexes have been compiled from recognized sources, both U.S. Government and commercial experts, and are utilized directly within the cost model. Examples of sources of commodity cost escalation data and forecasts: U.S. Bureau of Labor Statistics (BLS); London Metal Exchange (LME); Bloomberg; MEPS; Naval Center of Cost Analysis (NCCA); Royal Bank of Canada; MetalPrices.com; Forecasts.org; KITCO metals; and others.

These factors are used to escalate/de-escalate material cost for those specific commodities instead of using a single generic escalation/de-escalation factor for all commodities.

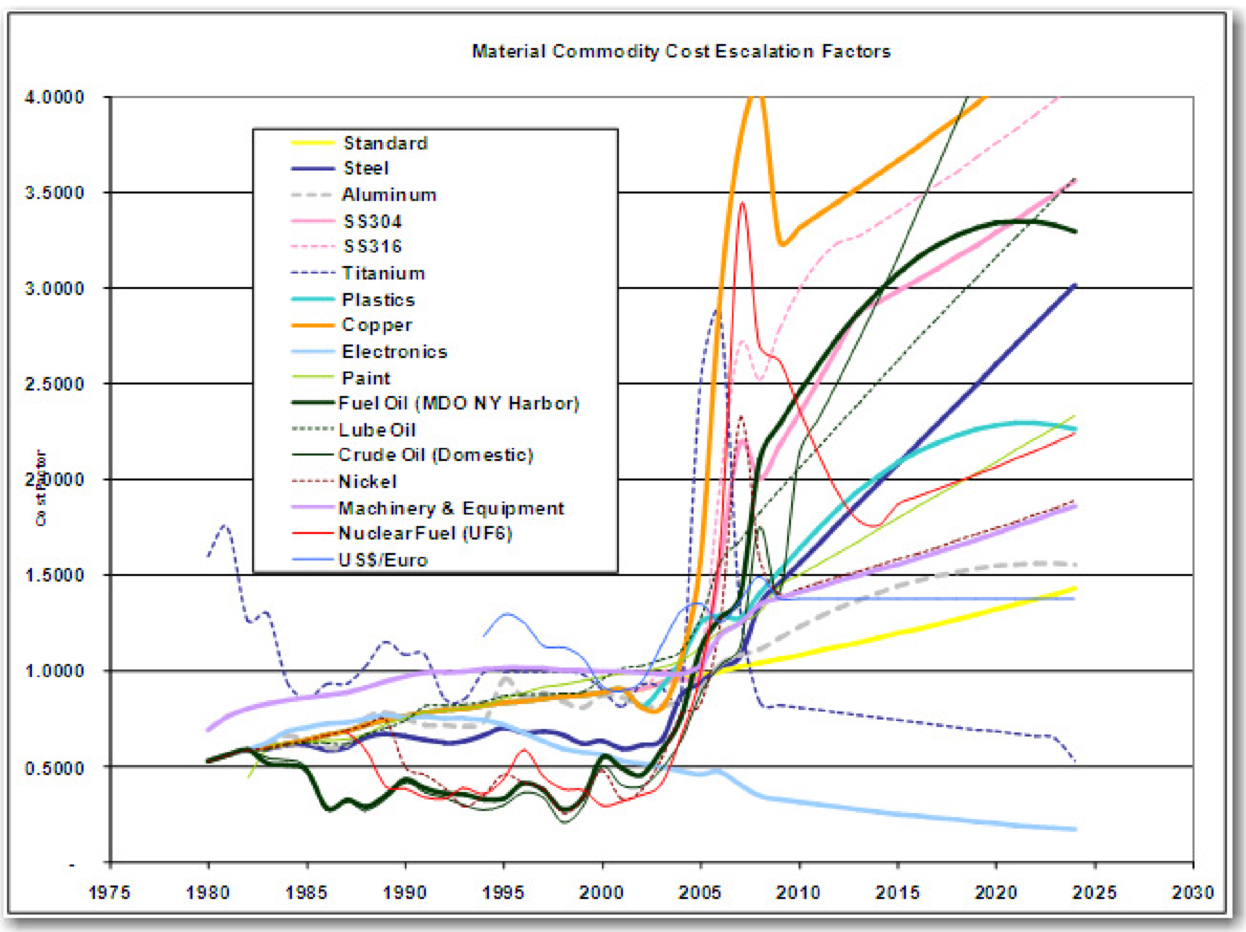

Figure 3: Sample of Material Cost Escalation Factors

Default Parameters

The cost models substitute default ship design parameters, developed from statistical data analyses, until actual design data can be provided. In this way, the cost estimate can follow the design evolution and can quickly produce cost changes due to many different design trade-off alternatives.

Figures 4 and 5 provide two examples of default parameters used where specific design information is not yet available. Other statistically derived design parameters will be used if not provided by the user.

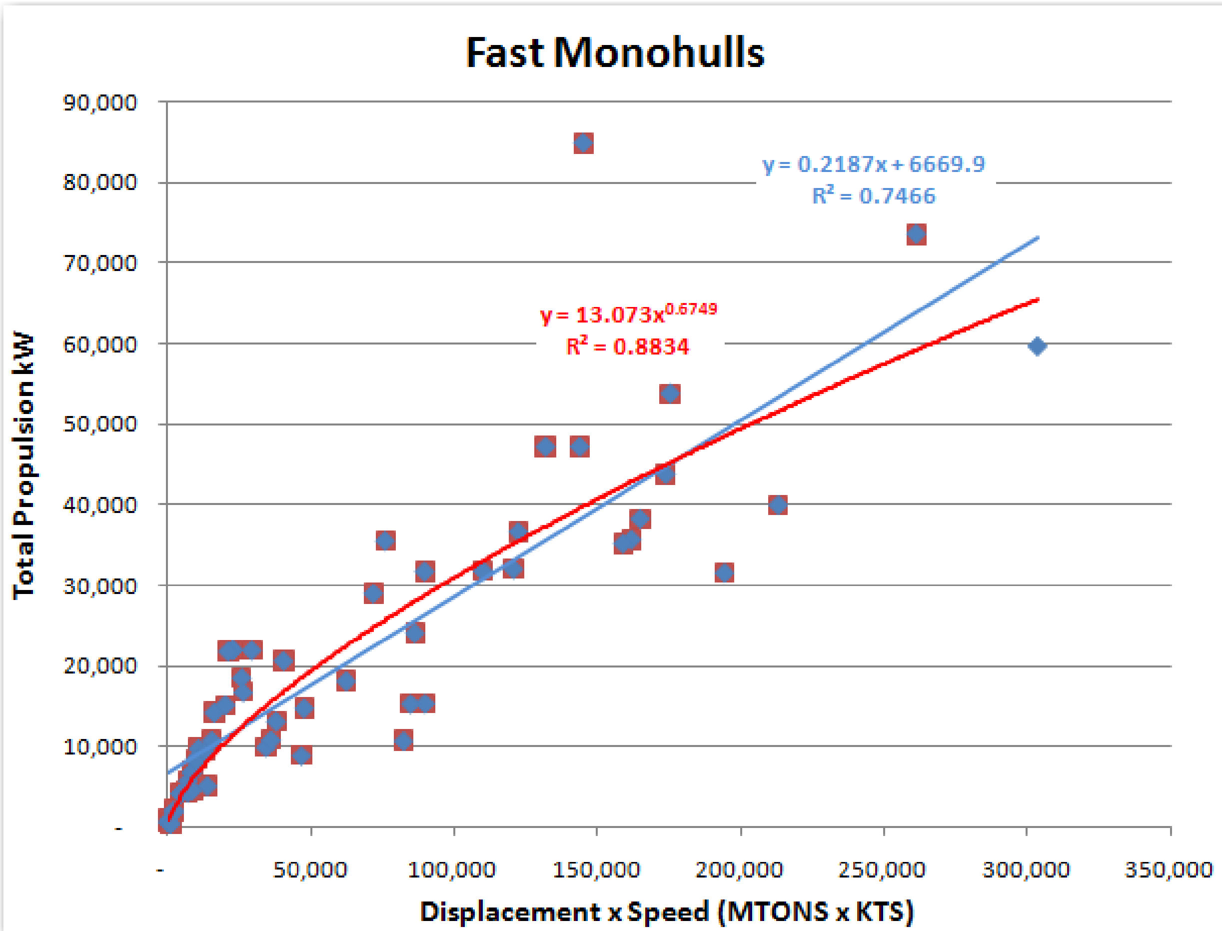

Figure 4: Sample Statistical Default for Propulsion Power

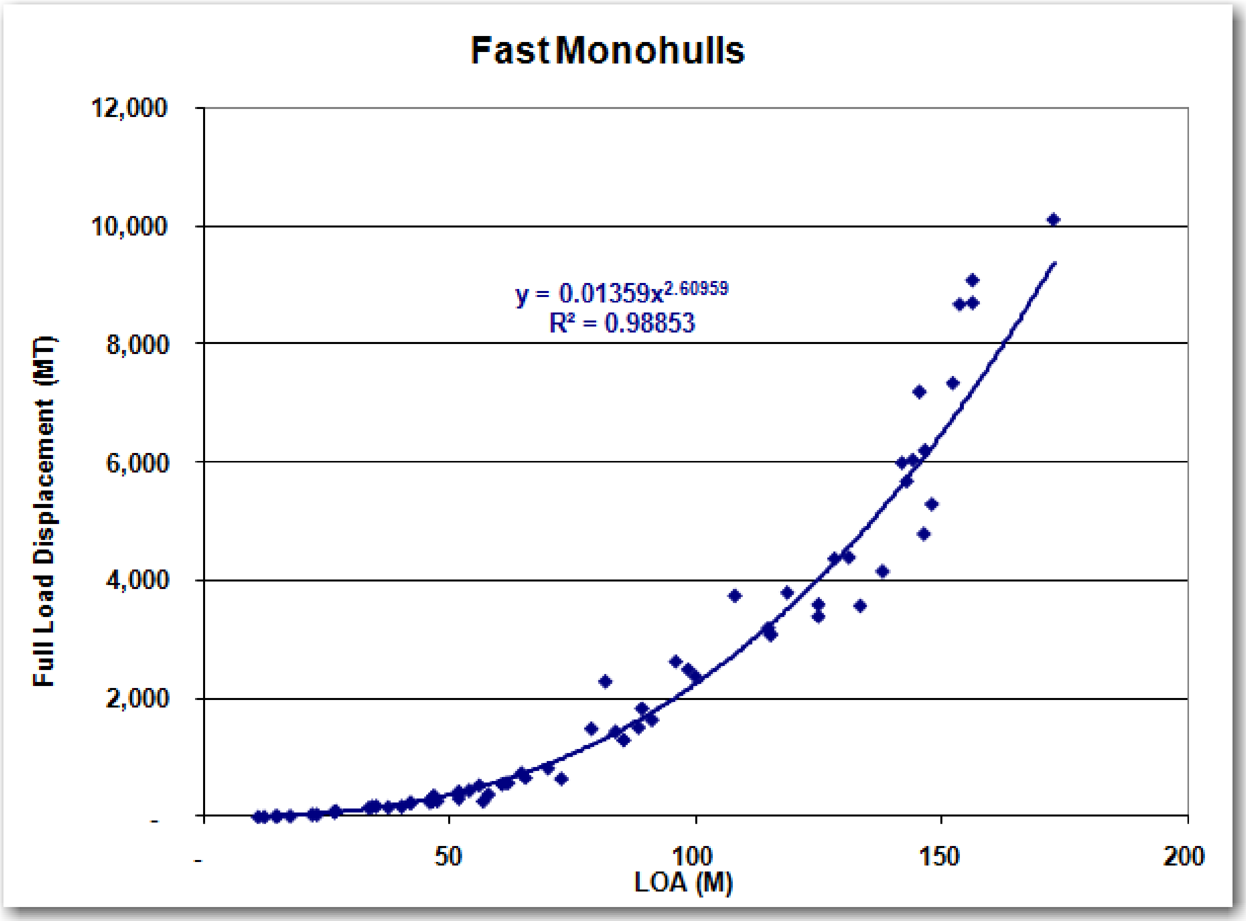

Figure 5: Sample Statistical Default for Full Load Displacement versus LOA

It should be recognized that the defaults developed and applied by the cost models are based strictly on statistical analysis of existing ship designs and do not necessarily satisfy conclusions made from rigorous naval architectural and marine engineering analysis for the design being estimated.

Effects of Build Strategy

One of the single-most important strategies to reduce construction costs is to perform work during the most productive periods of the overall construction process. This means, maximizing the amount of work performed in the controlled environments of the shops and minimizing the work aboard the ship. Shop work can be done undercover and offers much easier access to work areas with men, materials and equipment. Shop work also can be performed without the need for expensive staging.

This build strategy culminates in exploiting the cost-savings benefits of modular construction techniques. Modules can be developed in a wide variety of ways: outfit and equipment modules, hull assembly blocks, and outfitted hull blocks.

- Outfit and equipment systems can be designed and assembled as a complete module that then can be installed either on hull assemblies and blocks prior to erection or installed later on-board. Such modules are called outfit-on-units.

- Hull block assembly is the process of building the hull structure in modular form of building blocks. This assembly method replaces older methods that built structures on the building ways from the inside out (traditional "stick" building). Hull block construction saves time because it can be performed much more easily and with less expensive material handling and worker access costs.

By outfitting hull block assemblies, productivity can be enhanced even further. On-block work can be 30%-50% less expensive in labor costs than equivalent work done on-board ship. The cost models provide features for simulating these cost savings.

Extended Modularization

Shipbuilding modules may take on almost any number of configurations and extents. Hull blocks are modules that, as described above, benefit from reduced costs compared to older stick-built methods of assembly at the building ways. Outfitting these hull blocks offers further cost savings by allowing outfitting to occur at earlier stages of construction where work can be focused on a platen rather than occurring later on board.

Other types of modules carry the concept of early stage construction cost savings even further. On unit outfit may be as small as a single piece of equipment mounted on its foundation and ready to install on block or on board. Or, on unit outfit can be a complex assembly of equipment, piping, electrical and other systems all pre-mounted on a support structure.

The following are good candidates for modular construction:

1. Weapons modules (guns, missiles, ASW, electronics)
2. Propulsion plant & auxiliary systems modules
3. Electric generator modules
4. Accommodations modules
5. Masts & stacks
6. Hull blocks

Modules can cover a very wide spectrum of applications, sizes, and systems. Modules can include one or more pieces of equipment and machinery with foundations and other support structures; they may include sections of multiple ship systems such as piping, ventilation duct, local electrical systems, etc. Modules may be installed on other modules, on hull sub-assemblies, assemblies, and on hull blocks and finally directly on-board.

Extended modularization promises a number of benefits during ship construction and assembly:

1. Lower fabrication and assembly costs
2. Lower installation costs
3. Lower installation time thus shortening construction schedules
4. Reduced testing time thus shortening construction schedules

Additional savings in time and money are possible in maintenance, repair and upgrade programs.

Modularized Weapons Systems

Weapons modules (Figure 6) should enable about the same level of installation cost and schedule savings as should be expected for other ship hull, mechanical and electrical (HM&E) systems modules. Weapon systems modules have become an integral and very important design and build strategy for modern European combatants.

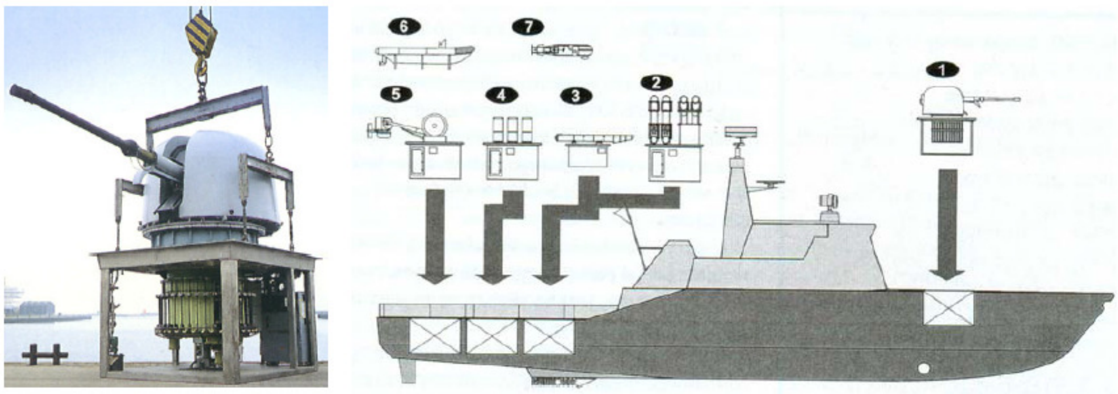

Figure 6: Modularizing Weapons Systems

A good example can be seen in the German MEKO class of ships (Figure 7). The MEKO ships use sockets of standard dimensions for installing weapons or other standardized equipment modules. These ships are built from large hull blocks and a wide variety of equipment and outfit modules. Examples of include modules for propulsion systems; power generation and supply; HVAC; masts; and specialized ship and weapons equipment. These modules are proving to be easier and less expensive to undertake replacement and repairs of damaged equipment and promise similar benefits for future modernization and upgrade programs as well.

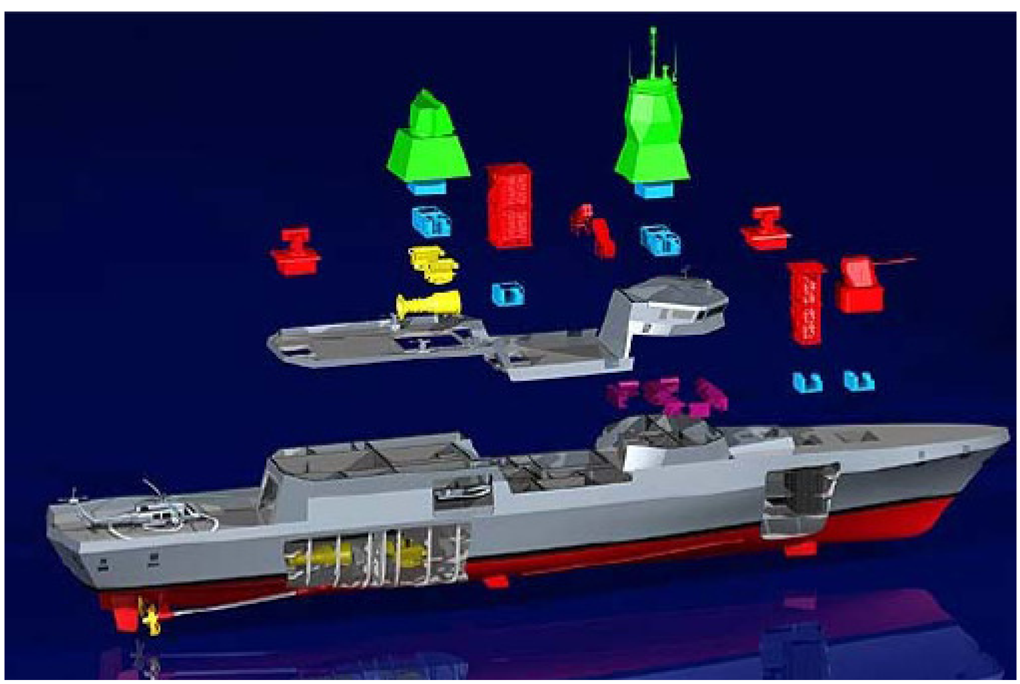

Figure 7: MEKO Module Technology

The cost models provide special options for simulating the improved installation efficiencies and cost reductions potential from extended modularization (Figure 8). These savings potentials are derived from actual shipbuilding cost studies across a wide range of outfit systems.

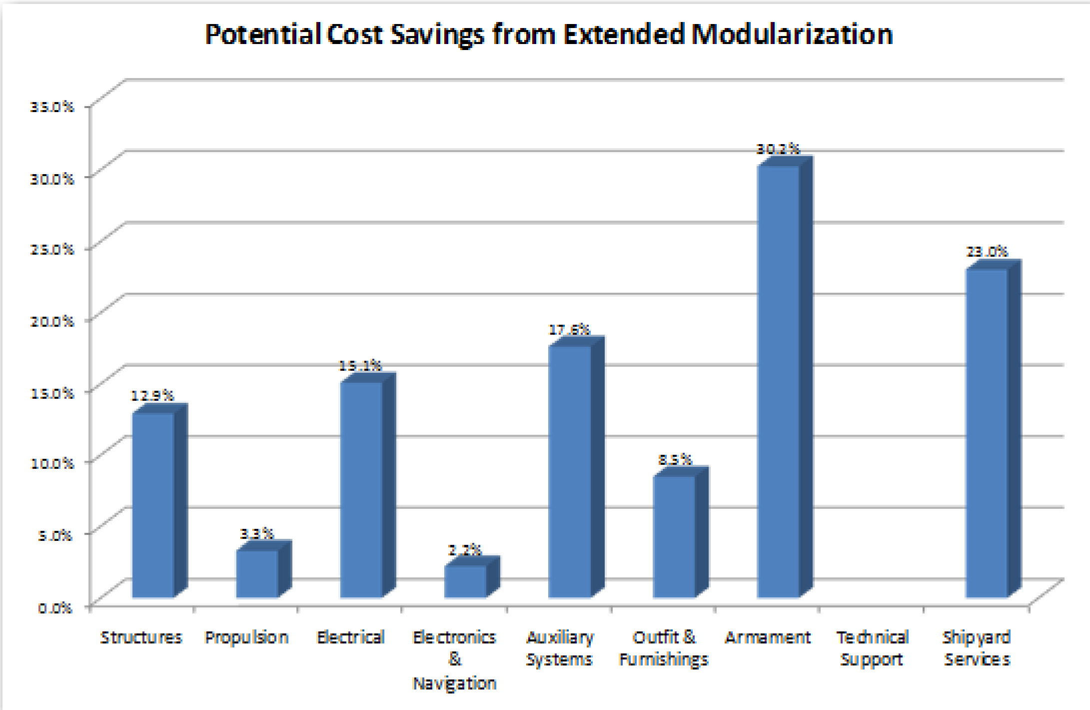

Figure 8: Sample Potential Cost Savings from Extended Modularization

Program Management Fees

The cost model has provisions for an overall contract Program Management Organization (PMO) to plan and manage a program that involves multiple parties assigned to execute various major aspects of the contract. For example, the program may identify separate companies for the detail engineering and production planning; for construction of major hull or equipment modules; and for construction of multiple hulls in parallel. All of these efforts should be coordinated and managed by an overall program manager.

The PMO typically is accountable for the overall management of the product and service results of the following functional team members:

1. The prime contractor shipyard (s)
2. The shipyard design and construction company
3. The major subcontracting shipyards, pre-outfitted hull or unit builders (from major hull modules to complete hulls)
4. The major detail design companies (smaller firms may subcontract to and be the responsibility of the major design firms or preferably pre-outfitted unit and hull builders)
5. The major ship system suppliers for turnkey machinery and electrical installations
6. The major logistic support companies providing ILS, maintenance and preparation for future repair
7. Any overall test and evaluation subcontractors

The cost models provide features for identifying PMO costs and fees.

NON-RECURRING DESIGN & DETAIL ENGINEERING COST ESTIMATES

Estimating costs for shipbuilding requires a good understanding of the costs involved in the up-front work required to design, engineer and plan for production.

These efforts are non-recurring, and their costs are typically spread equally among the number of ships involved in the construction contract. For series ship contracts, these efforts are likely to be more comprehensive than for one-off ship projects. However, over the course of a multiple ship program, the higher non-recurring costs may well result in lower average ship construction costs that one would expect from better engineering and more rigorous and effective production planning. The quality, completeness and timeliness of this technical work will largely determine the costs and schedules for production whether for one ship or multiple ships.

Non-recurring costs may include research, preliminary and contract design, detail production engineering and production planning (Figure 9).

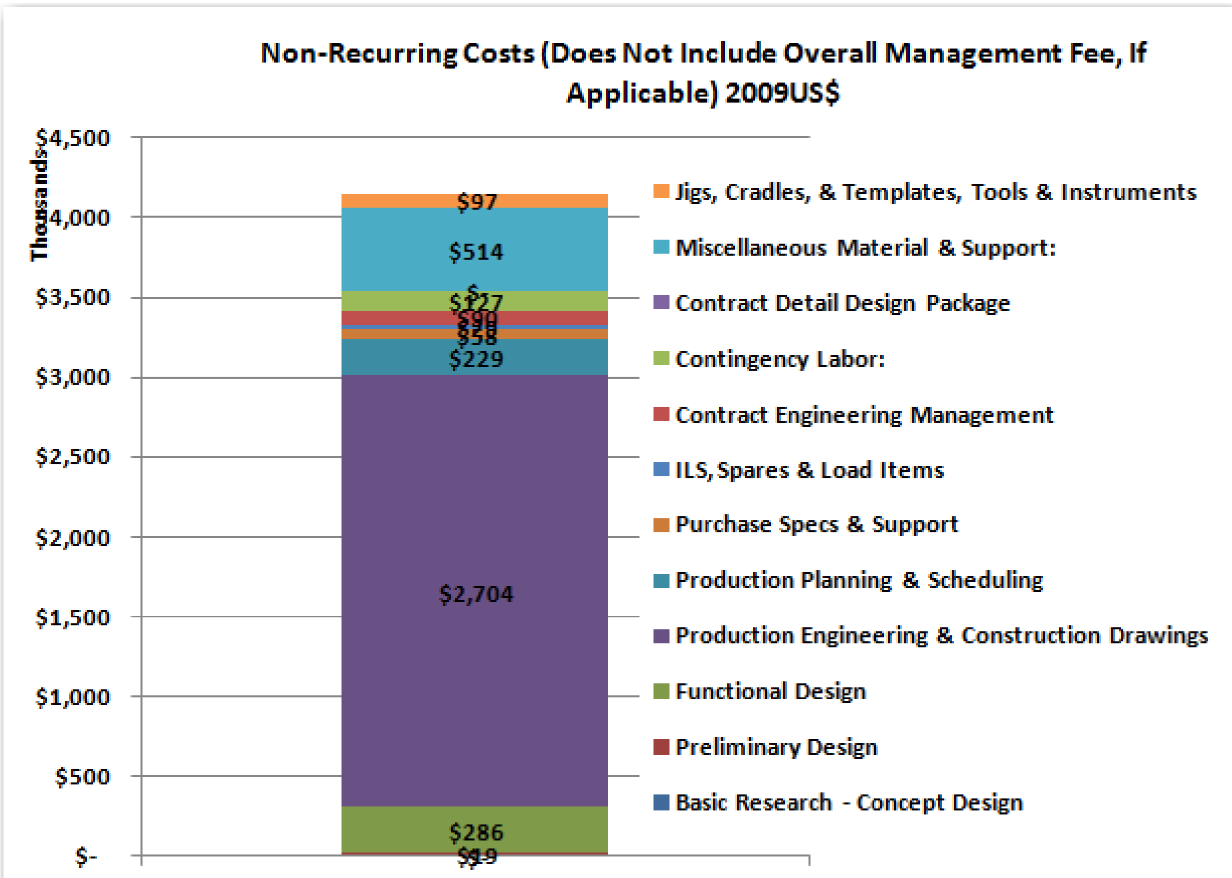

Figure.9: Work Breakdown of Non-Recurring Cost Efforts

U.S. Navy ship non-recurring costs are generally higher than for commercial ship programs. The following are examples expressed as percentages of production hours (not including shipyard support services):

1. Navy auxiliaries AO program 60%, and TAO 54%
2. Amphibious LHD program 65% and the LSD program 60% (LPD-17 program was much, much higher).

3. Research and Surveillance AGOR 20% and TAGOS 60%
4. Combatants incur even higher non-recurring costs on the order of 100% to 200%, depending on the complexity of the ship design and the number of ships being built that necessitates more engineering efforts to improve down-stream construction costs and delivery schedules.

Typically, U.S. Navy contracts catalog both recurring and non-recurring technical costs together under SWBS 800. Therefore, the majority of engineering costs appear for the lead ship. The cost models, instead, catalog only the recurring technical costs under SWBS 800 (engineering change orders, refined production engineering changes, etc.) and catalogs non-recurring costs under a separate "project" WBS. This separation allows the non-recurring costs to be easily allocated to all ships of a series program.

The cost models offer an option to estimate design royalties and/or out sourced engineering efforts.

RECURRING COST ESTIMATES

Recurring costs include all basic construction costs for each ship. For series ship construction programs costs are estimated for follow-on ships by applying estimated learning curve factors for labor and potential material cost savings.

The recurring cost estimate is broken down into cost categories similar to the Navy's Ship Work Breakdown Structure (SWBS), Figure 10. Differences lie primarily in SWBS 200 which carries only propulsion machinery items and their installation. Piping systems for propulsion are cataloged under SWBS 500 for auxiliary systems along with all other piping systems for the ship.

SWBS 300 carries all non-propulsion electric generation equipment for ship services, as well as all electrical distributed systems, lighting, etc.

SWBS 800, Technical Services, includes only technical support for change orders, etc. after non-recurring activities are complete. A figure of approximately 8% of production labor hours (SWBS Groups 100-700) is a typical figure applicable to a North American commercial shipyard for contracts that have very limited change orders and redirections of the build strategy.

Technical support services is expected to be more for the combatant shipbuilder due to the added effort required to address expanded procedures to satisfy U.S. Navy technical and contractual requirements.

SWBS 900, Shipyard Production Support Services include all the miscellaneous efforts required to support production. A major component of this cost lies in supervision and production control. These shipyard support efforts can be a difficult source of cost to control because it is mostly level of effort. However, they can be reduced by implementing a number of modern shipbuilding methods:

1. Early stage outfitting (on unit and on block) eliminates considerable support costs required for on board outfit efforts.
2. Early stage outfitting minimizing or eliminating scaffolding and related support costs.
3. Improved material flow to work areas minimizes material transport costs.
4. Higher level of work skills and higher quality of production engineering reduces supervision and quality assurance costs.

NOTE: The cost model places costs for producing jigs and templates, etc. under the Non-Recurring Detail Production Engineering and Planning described above.

A figure of approximately 20% of production labor hours (SWBS Groups 100-700) may be used for an estimate of production services. This is a figure not atypical of North American commercial yards that employ reasonable control over this level of effort and follows a regimen that minimizes unnecessary costs.

Shipyard production support services is expected to be more for the combatant shipbuilder due to the added effort required to address expanded procedures in order to satisfy U.S. Navy technical and contractual requirements.

An additional SWBS 1000 is used for external fees (ABS, financing fees and MARAD title XI when applicable, etc.) and for various shipbuilding risk insurance costs, warranty bonds, etc. This SWBS group also includes a contingency cost item for margin, change orders and for yet-undefined ship system requirements.

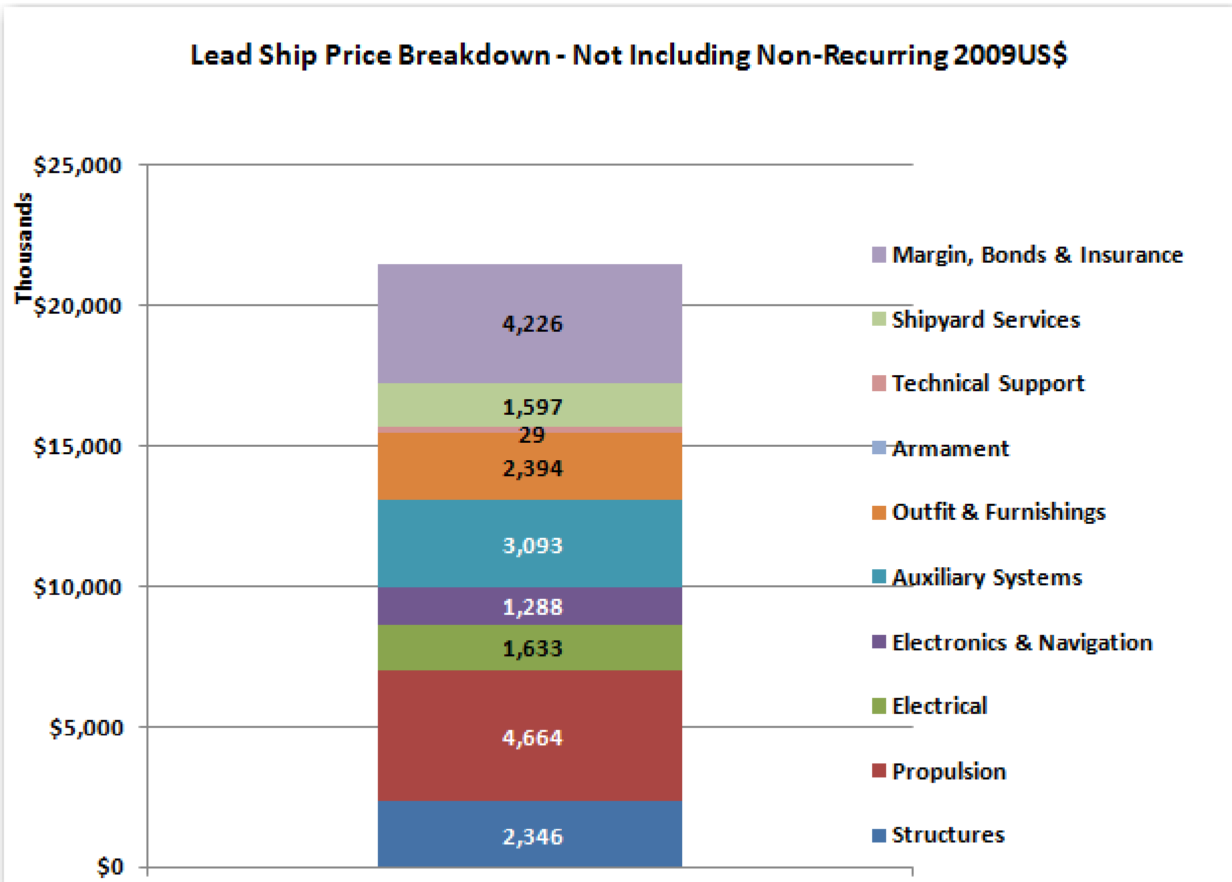

Figure 10: Recurring Cost Estimate Work Breakdown Structure

Additional Cost Issues

The cost model addresses costs specific to ship design, engineering, planning and construction and normally does not estimate the cost for ancillary items or services that may be included in shipbuilding contracts. The cost model, however, does have features for adding others on a case by case basis:

- Margin (expressed as a percentage of total cost).

- Mark-up (expressed as a percentage of total cost) likely to be added by the shipbuilder if new work would strain available resources due to a back-log of existing contracted work.
- Change Orders (expressed as a percentage of total cost) that are likely to be required after contract award.
- Program Costs (expressed as a percentage of total cost) if included in the total contract cost estimate. Contingencies (expressed as a percentage of total cost) to covered for systems and components not yet identified.

These cost items are catalogued under SWBS 1000.

The cost estimates for recurring costs are broken down into details that are cataloged by a modified U.S. Navy SWBS groups.

Lead Ship Construction Estimate

The cost models provide a lead ship cost estimate summary (Figure 11) that identifies most of the basic top level information about the non-recurring design and engineering and lead ship construction. Additional information summarizes the cost risk. Many other graphical charts are available that summarize labor hours, material costs, weights, etc.

Mono Hull Patrol Boat/Cutter/Frigate

(Model Version March 2009)

% Margin	-	%
%Mark-Up	-	%
% Change Orders	-	%
% Program Costs	-	%
% Contingencies	16.00	%

Ship Type: 46m Fast Patrol Boat

Version: A

Date: 17-Sep-09

NON-RECURRING COSTS

Basic Research - Concept Design	$	-
Preliminary Design	$	18,606
Functional Design	$	282,827
Production Engineering & Constr	$	2,704,208
Production Planning & Scheduling	$	229,062
Purchase Specs & Support	$	68,172
ILS, Spares & Load Items	$	29,088
Contract Engineering Manageme	$	90,218
Contingency Labor:	$	127,409
Contract Detail Design Package	$	-
Miscellaneous Material & Suppor	$	614,088
Jigs, Cradles, & Templates, Tools	$	98,513
TOTAL NON-RECURRING COSTS:	$	4,163,379

Pricing:

Shipbuilder Economic Mark-Up/Down:	0.0%		
Technical Wage $/Mhr:	$ 28.89	$ 65.00	w / overhead
Production Wage $/Mhr:	$ 22.22	$ 50.00	w / overhead
%Overhead:	125.00	%	
%G&A Labor:	-	%	
% G&A Material:	10.00	%	
% Profit:	12.00	%	
%Contingency Margin	57.00	%	
Navy C4ISR	No		
Jones Act Premium Material Factor:	No	1.00	
Current Year:	2009		
Additional Material Escalation:	1.00	1.000 = none	
Shipyard Material Cost Factor:	1.21	MIL SPEC Prem.=1.21	
Combined Material Cost Factor:	1.21		

Non-Recurring Engineering & Production Planning

	Standard Work Week:		40.00	hours/week
	Labor Rates:			
255%	Senior Professional/Manager	$	143.77	per hour
257%	Engineer	$	128.36	per hour
225%	Designer/Draftsperson/Planner	$	112.99	per hour
123%	Clerical	$	61.82	per hour
247%	Contingency (weighted average)	$	123.74	per hour

	Shipyard	Fab/Assy Mod'les
Shipyard Tech Support Labor Factor:	1.1000	
Steel Productivity Factor:	1.0000	1.000
Outfit Productivity Factor:	1.0000	1.000
On-Block Paint Factor:	0.9600	40 % Hours On Block

Estimated Schedules

Est. Detail Engineering Time:	8.00	Months	
Est. Construction Time:	10.00	Months	
Overlap:	2.00	Months	20.0%
RM $ Men/Month: 23	0.08	Months	0.8%

	SWBS	Weight	M-Hrs	Modular	Production	$	$	$ G&A	2009	$ G&A	$ Profit	$	$
	Group	M Tons	Per M ton	M-Hrs	M-Hrs	Labor	Overhead	Labor Only	$ Material	Material Only	Labor + Material	Total	Cum.Total
Structures	1	170.5	111.97	3,843	19,059	509,554	636,950	-	561,744	56,174	251,338	2,345,821	
Propulsion	2	25.5	36.66	6,647	1,056	171,157	213,946	-	3,435,623	343,562	499,715	4,664,003	
Electrical	3	14.8	65.52	2,201	971	70,494	88,117	-	1,181,415	118,142	174,980	1,633,147	
Electronics & Navigation	4	2.3	532.37	2,040	1,200	72,000	90,000	-	898,275	89,827	138,012	1,288,115	
Auxiliary Systems	5	58.5	52.50	5,577	3,071	192,177	240,222	-	2,117,761	211,776	331,432	3,093,369	
Outfit & Furnishings	6	15.3	121.14	1,932	1,856	84,214	105,268	-	1,770,621	177,062	256,460	2,393,625	
Armament	7	4.9	11.46	95	56	3,340	4,175	-	16,323	1,632	3,056	28,526	
Technical Support	8	8.0%	7.35		2,150	62,965	78,706	-	30,250	3,025	20,993	195,939	
Shipyard Services	9	20.0%	18.45		5,449	121,086	151,357	-	1,045,193	104,519	171,055	1,596,510	
Margin, Bonds & Insurance	10	-	-		-	-	-	-	3,430,158	343,016	452,781	4,225,954	
Lead Ship Totals:		295	118.27	22,333	34,928	$ 1,287,016	$ 1,608,770	$ -	$ 14,790,364	$ 1,479,036	2,299,822	$ 21,465,009	$ 21,465,009
Non-Recurring Costs:	% Total Lead Ship G 1-7 Man-Hours:			60%	28,631	$ 3,542,778	$ -	$ -	$ 610,601	$ -	488,406	$ 4,861,784	$ 26,116,794

Technical Support:	1.27%	Production $ Costs
Shipyard Services:	10.34%	Production $ Costs
Fees & Insurance:	27.36%	Production $ Costs
Non-Recurring Costs:	30.12%	Production $ Costs
Production Costs (1-7):	$ 15,446,606	72.0% GR 1-10

Production Hrs/LSW:	188.80

	Estimated Cost for Prime Contractor Management Team:	$ -	
	Over-All Program Management Fee: 0.0%	$ -	
	Total Price with Prime Contractor Management:	$ 26,116,794	
	Estimated Construction Risk:	$ 1,979,684	w/o Profit
	Estimated Rework Risk:	$ 54,898	w/o Profit
0.80	Shipyard Experience Rating (0-1):	$ 980,688	w/o Profit
0.80	Engineering Performance (0-1):	$ 2,317,888	w/o Profit
	Production Schedule Cost Risk:	$ 313	w/o Profit
	Total Price with Risk:	$ 31,450,140	w/o Profit

Figure 11: Cost and Price Estimate Summary Report

The cost models contain a full array of ship system details that can be turned on and off as required. Quantities and density factors can be applied to selected details by the user as well.

Various detail tabular reports can be generated as shown in Figure 12.

Cost Item	Description	Labor Hours	Labor Cost	Material Cost	SubCon Hours	SubCon Cost	Travel Cost	Direct Cost	Taxes	Indirect Cost	Total Cost	Profit	Total Price
Project 46mPB 46 Meter CG Patrol Boat													
Group 3 - Electrical													
Account 308 - Lighting													
Center SY - Production Centers (Non-Structural)													
308.1	Lighting - Exterior Decks	0	0	1,211	0	0	0	1,211	0	121	1,332	160	1,492
308.2	Lighting - Machinery space	0	0	561	0	0	0	561	0	56	617	74	691
308.3	Lighting - Deck House	0	0	1,041	0	0	0	1,041	0	104	1,146	137	1,283
308.4	Lighting - Habitation Areas	0	0	5,178	0	0	0	5,178	0	518	5,695	683	6,379
	Account: 308 Totals	**0**	**0**	**7,991**	**0**	**0**	**0**	**7,991**	**0**	**799**	**8,790**	**1,055**	**9,845**
Account 310 - Electrical Labor													
Center SY - Production Centers (Non-Structural)													
310.1	Electrical Labor - Stern	17	389	0	0	0	0	389	0	447	836	100	936
310.2	Electrical Labor - Machinery Space	224	4,999	0	0	0	0	4,999	0	5,749	10,749	1,290	12,039
310.3	Electrical Labor - Deck House (Not ir	251	5,603	0	0	0	0	5,603	0	6,443	12,046	1,446	13,491
310.4	Electrical Labor - Habitation Areas	1,249	27,862	0	0	0	0	27,862	0	32,041	59,902	7,188	67,091
310.5	Electrical Labor - Forepeak	44	992	0	0	0	0	992	0	1,141	2,133	256	2,389
310.6	Electrical Labor - Forebody Deck	23	518	0	0	0	0	518	0	596	1,114	134	1,248
	Account: 310 Totals	**1,809**	**40,363**	**0**	**0**	**0**	**0**	**40,363**	**0**	**46,417**	**86,780**	**10,414**	**97,193**
Account 312 - Electrical Systems & Components													
Center SY - Production Centers (Non-Structural)													
312.1	Auto dial telephones	0	0	46,953	0	0	0	46,953	0	4,695	51,648	6,198	57,846
312.2	Battery chargers	0	0	3,521	0	0	0	3,521	0	352	3,874	465	4,338
312.3	Bracket fans	0	0	4,108	0	0	0	4,108	0	411	4,519	542	5,062
312.4	Disconnect switches	0	0	47	0	0	0	47	0	5	52	6	58
312.5	Emergency stop stations	0	0	1,878	0	0	0	1,878	0	188	2,066	248	2,314
312.6	Fire screen door magnets	0	0	4,695	0	0	0	4,695	0	470	5,165	620	5,785
312.7	Floodlights	0	0	29,346	0	0	0	29,346	0	2,935	32,280	3,874	36,154
312.8	General alarm system	0	0	35,215	0	0	0	35,215	0	3,521	38,736	4,648	43,385
312.9	Hospital call system	0	0	3,521	0	0	0	3,521	0	352	3,874	465	4,338
312.10	Lamps	0	0	10,564	0	0	0	10,564	0	1,056	11,621	1,395	13,015
312.11	Main & Emergency Switch Boards	0	0	18,762	0	0	0	18,762	0	1,876	20,638	2,477	23,115
312.12	Navigation light panels	0	0	7,747	0	0	0	7,747	0	775	8,522	1,023	9,545
312.13	Navigation lights	0	0	7,043	0	0	0	7,043	0	704	7,747	930	8,677
312.14	Public address system & fog gong	0	0	50,475	0	0	0	50,475	0	5,047	55,522	6,663	62,185
312.15	Power Panels	0	0	29,346	0	0	0	29,346	0	2,935	32,280	3,874	36,154
312.16	Power Receptacles	0	0	2,935	0	0	0	2,935	0	293	3,228	387	3,615

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Figure 12: Sample Detail Estimate Cost Item Listing (SWBS Sort Order) Showing Extended Cost and Price

Multiple Ship Cost Estimates

The cost models estimate costs for follow-on ships (Figure 13) according to a user-defined labor hour learning curve and sequentially allocating the non-recurring costs equally to each ship of the series. Since many multiple ship programs have costs for the second ship that does not follow such a learning curve, an option allows the second ship to have a manually assessed learning, if any, and the defined learning curve applied to the third and remaining follow ships.

Learning depends greatly on the quality and completeness of the engineering and production planning. Large learning typically can be experienced when the lead ship suffers many problems in this regard, only to see the follow ships benefit from efforts to correct these problems. The degree of learning also will be less if the shipyard employs standard engineered interim products and manufacturing processes. Getting it right the first time means that the learning process was essentially done at an earlier period of time. There is a lot of "ifs" involved in trying to estimate learning as it involves a lot of how well everyone performs, how innovative is the shipyard in maximizing productivity, and how many changes are required from ship to ship both from within the shipyard and from without.

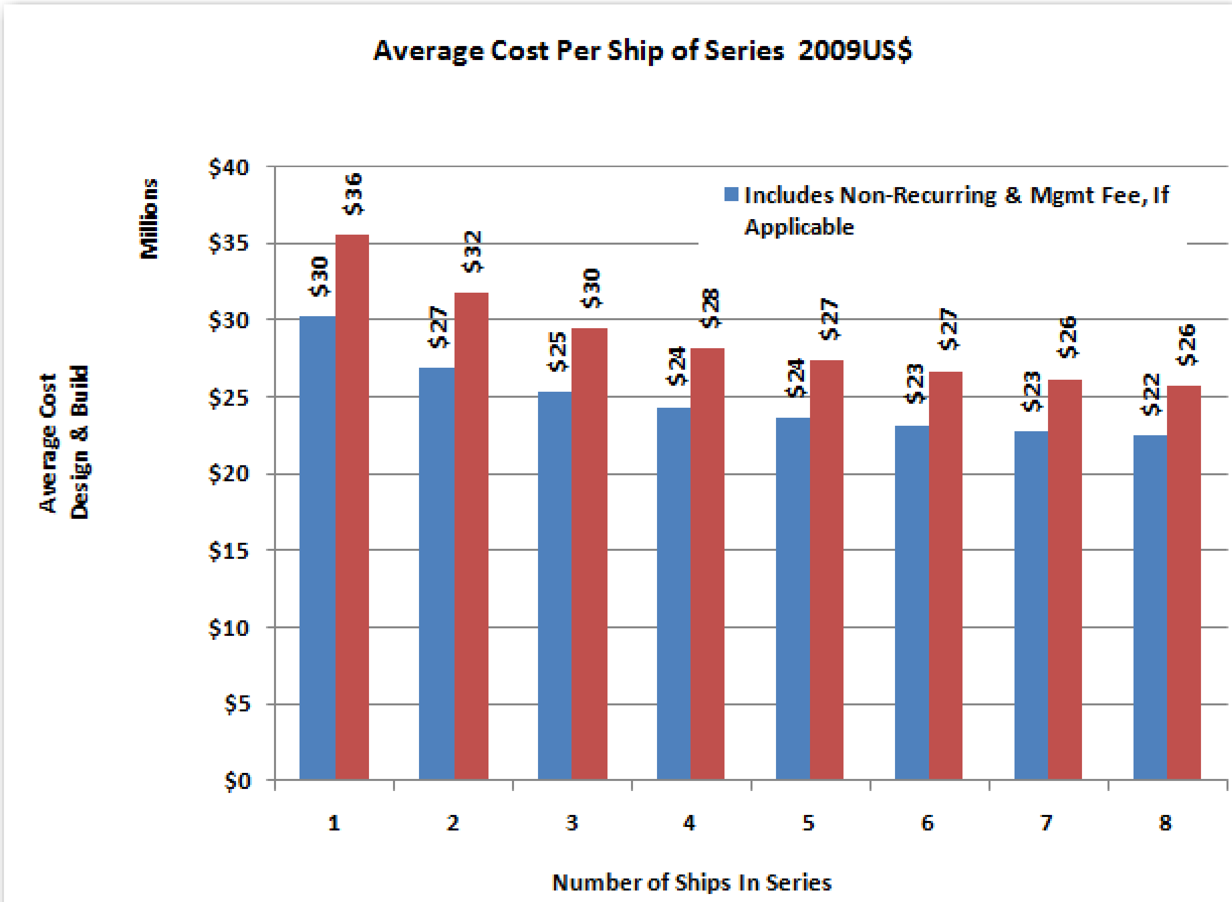

Figure 13: Estimates for Multiple Ship Production Programs

Material Cost "Learning" (Discounts)

The cost model has provisions for introducing anticipated material cost discounts for series ship programs.

COST RISK ESTIMATES

The cost risk computations used in the models are sensitive to expected technical, material, and construction risk and performance issues (Figure 14). The estimates further reflect the impact on performance of schedule, overlapping engineering with production and relative outfit density of the ship design.

The models develop cost risk within several focus areas:

1. Cost risk of applied CERs
2. Cost risk due to shipbuilder's relative experience
3. Cost risk due to compressed production schedule
4. Cost risk due to anticipated performance problems of detail engineering including unknown technology issues
5. Cost risk of rework due to immature and changing detail engineering when overlapping with production

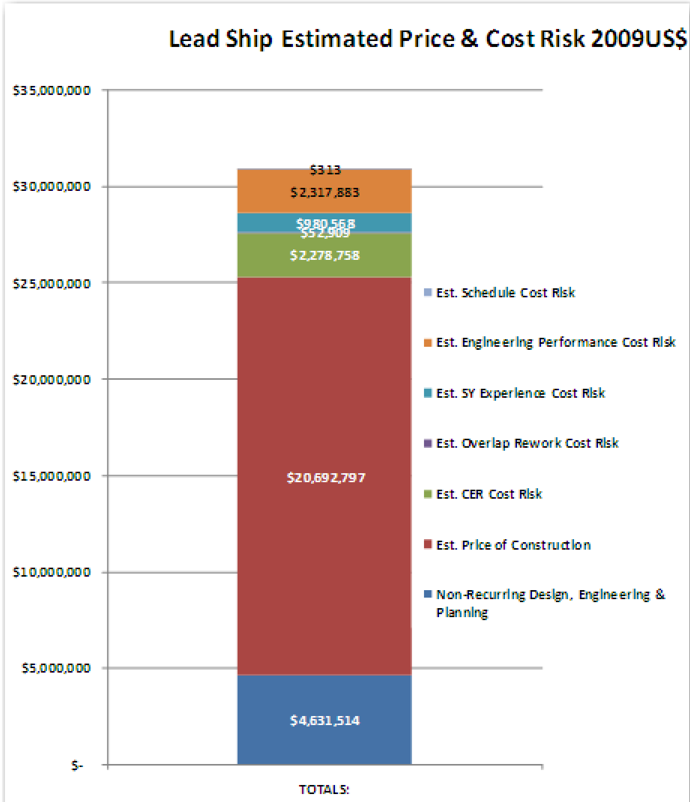

Figure 14: Sample Chart Showing Cost Risk Relative to "Should" Costs for Non-Recurring Design & Engineering and Lead Ship Construction.

ESTIMATED MANPOWER REQUIREMENTS

The cost models automatically generate estimated engineering and shipyard production manpower requirements within the schedules determined by the user (Figure 15). This is a good cross-check on the defined schedule and the estimated labor hours.

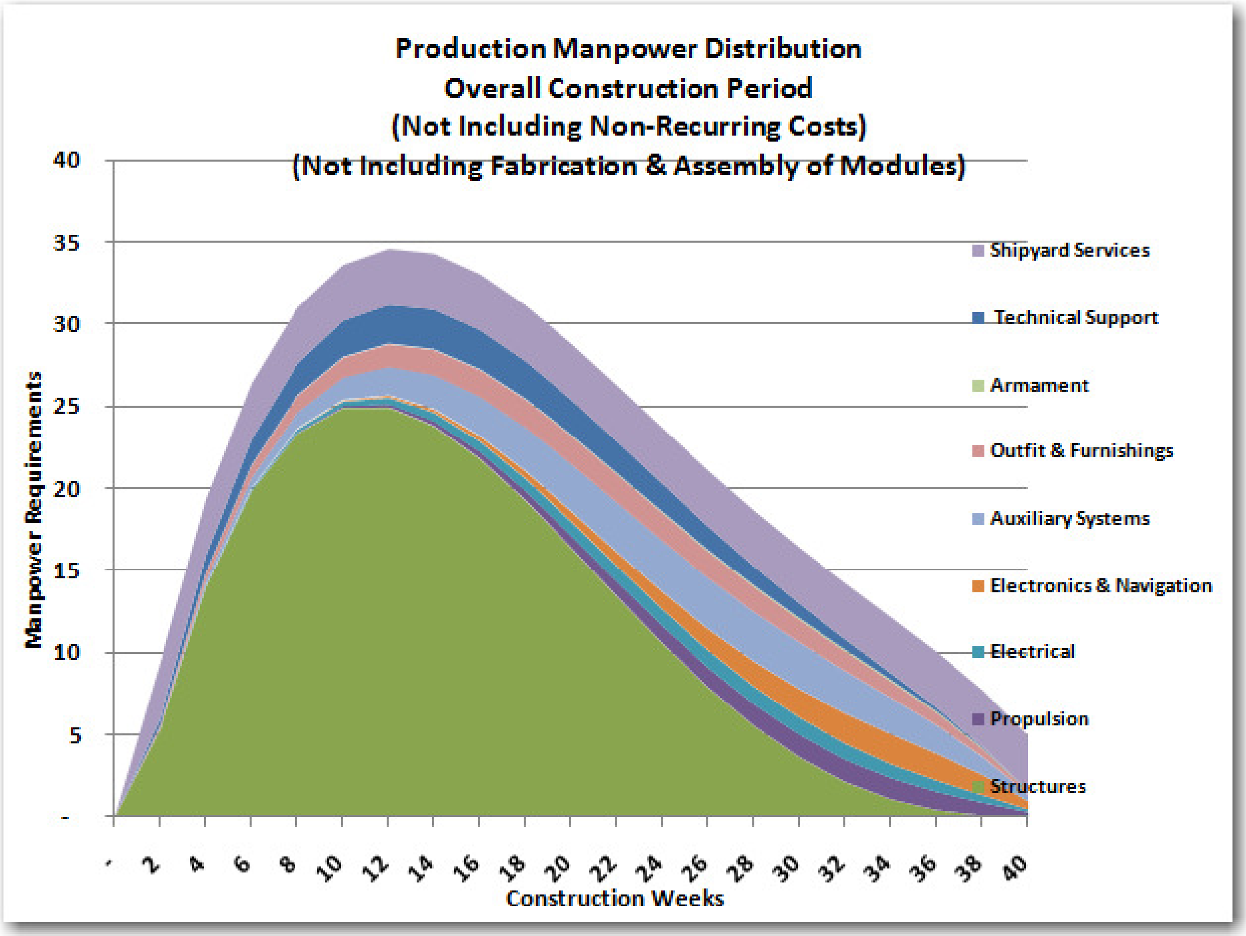

Figure 15: Sample Lead Ship Construction Manpower Estimate

LIFE CYCLE COST ESTIMATES

For life cycle costs, annual estimates are generated for capital financing and return on equity; maintenance; salvage/resale; insurance; administration; supplies and crew (Figure 16). Fuel, port and drayage costs complete the operational cost estimates where average voyage scenarios (speeds and distances) are defined by the estimator. The cost models develop Required Freight Rates (RFR) on the basis of unit (trailer, TEU, barrels, etc.) voyage cost, tonnage, and/or equivalent statute land miles. The models allow sensitivity cost studies such as tracking RFR versus fuel costs and many other design, construction and operational parameters.

The cost models offer benefits to non-commercial applications as well. Speed and power requirements carry costs of fuel consumption. The cost models can relate changes in operational costs where these and other parameters such as manning levels are changed. In addition, the cost models can generate cost estimates for transporting military cargos that can be compared against transportation offered by alternate means such as by air.

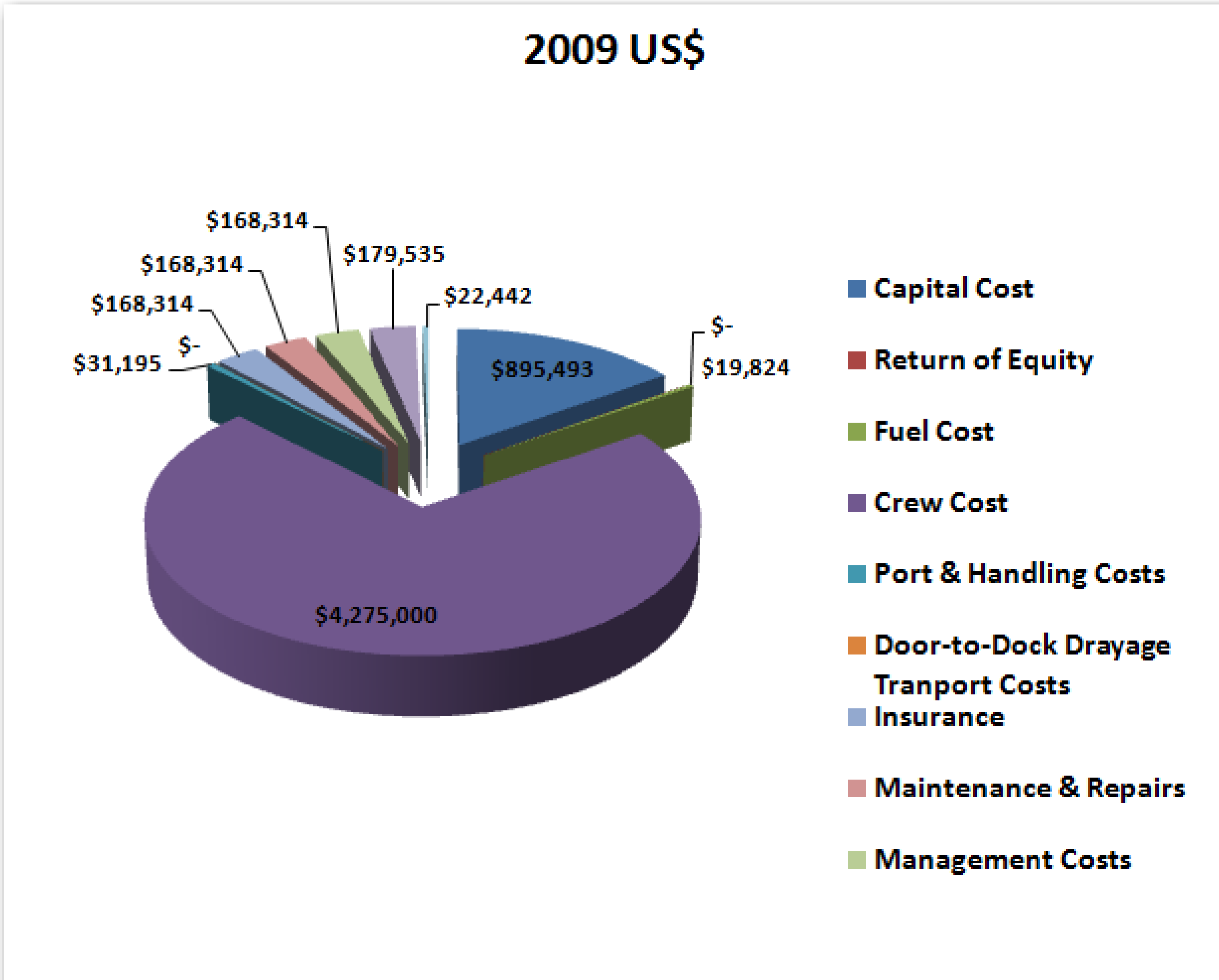

Figure 16: Sample Estimates of Annual Capital, Operational & Maintenance Costs

CONCLUSION

Use of cost estimating tools like the cost models described above provide a valuable compliment to the ship design process. Where cost is a critical factor, such tools enable the ship designer to explore a range of different design options and render results that not only improve ship performance but at a reduced cost, both short term and potentially long term. These tools provide the designer a quick assessment of cost regardless of the stage in the design development.

The ability to focus on specific areas of cost risk provides new opportunities to minimize their impact long before they can come into play. Without some visibility of where to reduce risk, potential problems too often result in construction programs that are in serious cost and schedule jeopardy.

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