Looking for Cost Drivers

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Abstract – **The effort to develop a successful and profitable shipbuilding bid requires developing a realistic cost estimate that addresses not only the ship owner's requirements, but also the capabilities of the shipbuilder to produce the product at a competitive price. This effort entails identifying, at a minimum, the major sources for costs and ensuring they are adequately estimated and appropriate for the bid requirements. These major sources are often called Cost Drivers.**

INTRODUCTION

Designing and building a modern ship is a complicated business involving procurement of many different materials and subcontractors synchronized with various production fabrication, assembly and testing processes. Each of these elements need to be carefully planned and coordinated, and each adds to the cost of the final product: the delivered ship.

Government agencies planning new shipbuilding programs are anxiously looking for how to satisfy their ship mission requirements within the limited funding levels available.

Commercial ship owners have financial objectives to meet the challenges of their business markets and maximize a return on investment.

Ship designers need to satisfy the ship owners ship performance requirements, and generate an engineered design that is more producible, easier and less costly to build. The management of the design and engineering processes further need to plan its efforts to directly support the shipbuilder and its ability to more efficiently execute the fabrication and assembly processes.

Shipbuilders need to offer ship products that can favorably compete against other shipbuilders on the open markets and satisfy the general financial and construction requirements imposed by the customer. The shipbuilder further needs to review carefully steps to minimize cost and schedule risk: specifically, cost risks from potential problems with engineering and production performance.

All of these special interests place a very heavy focus on one single element that affects them all: cost

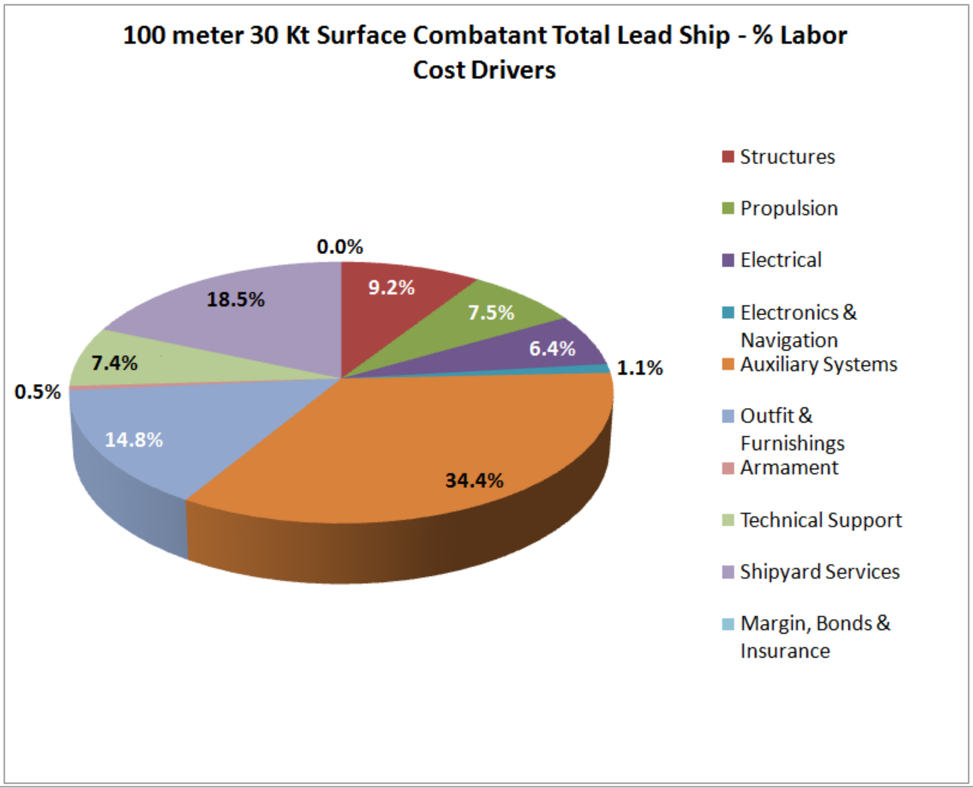
This paper provides a general focus on the primary drivers of costs that directly impact the success or failure for a ship design/build program.

Within what typically is a limited time frame for cost evaluations, the prudent shipbuilder needs to at least review the costlier elements of its program proposal. These large cost items are called cost drivers, and their review can open up new opportunities to mitigate their costs, even open up innovation for applying new technologies and build strategies that can improve the program's overall price and/or improve the performance of the ship design in the water and reduce costs over the life of the vessel.

SPAR, a long-standing company specializes its products and services on helping ship designers and shipbuilders better manage their costs. This discussion illustrates a many faceted approach to reviewing a program cost estimate and identifying what cost drivers are most significant. The discussion describes typical" hard cost drivers" such as expensive machinery and equipment to "soft cost drivers" such as the producibility of the ship design and outfit density. Likewise, shipbuilder's productivity and the cost/schedule performance of the engineering effort can be critical drivers of cost too.

EXAMPLE 100 METER OFFSHORE PATROL VESSEL

Using a well-established estimating cost model for ship design and construction, the following charts show percentage breakouts of labor hours and material costs for a sample 100meter patrol vessel. In this case, the cost drivers are identified only at the summary levels of the work breakdown structure. They show relative cost drivers for labor and for equipment and materials. More often than not, the cost drivers for each do not reflect the same proportional cost.



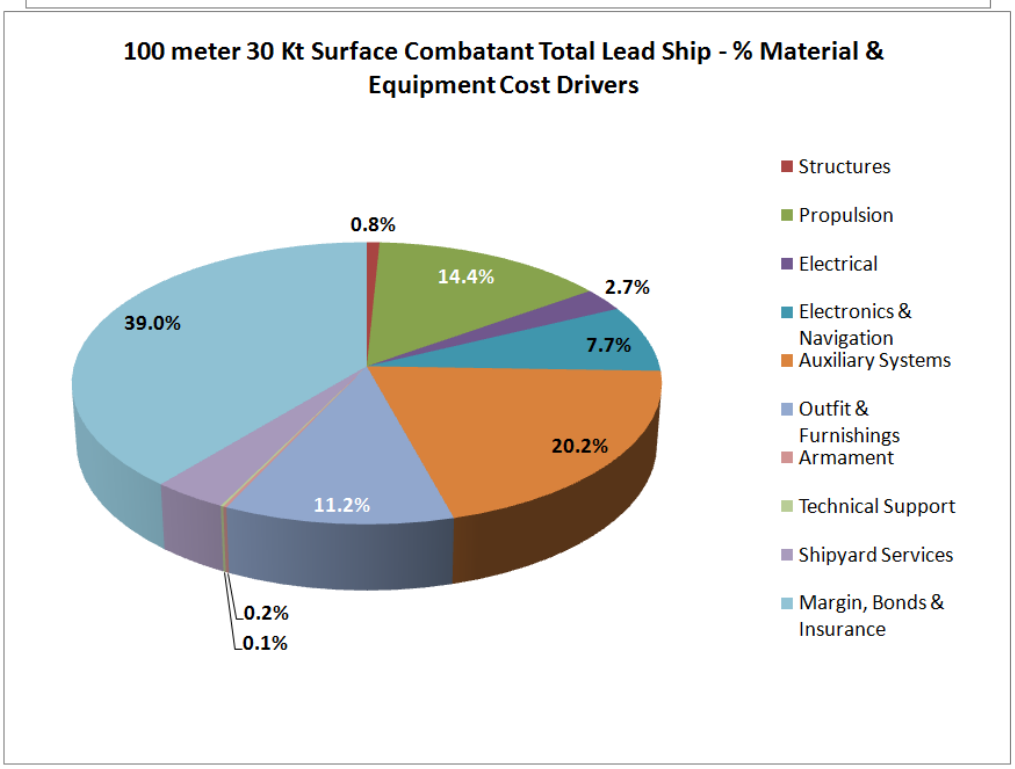


Figure 1: Average Percent Breakout of Production Labor Hours & Material/Equipment Costs

This example offshore patrol boat is a non-frills design.

1. While structural labor is less than 10% total production hours, the material costs are minimal, less than 1%, compared to total construction material costs. Structural costs will become more of a cost driver with the use of more exotic materials (e.g., composites).
2. Propulsion costs gain more impact when hull speeds are increased, especially above 28-30 knots. "Green" energy features add about 30% more to the cost of machinery.
3. Electrical systems are usually a modest cost driver unless large integrated electrical systems are in the design. Military redundancy for electrical systems about double its cost. While use of LED lighting increases lighting construction costs, this technology reduces power generating demands and operating costs.
4. The electronics is relatively light in this particular demonstration case. However, a full capability military C4ISR is considerably more expensive and can easily become a major cost driver.
5. Auxiliary systems costs are pushed primarily by HVAC and piping. HVAC can become quite expensive for accommodating large cooling loads for advanced weapons systems. Chemical, Biological, Radiological and Nuclear (CBRN) mitigation features about double general HVAC costs. Designing for shock will about double the cost for piping systems.
6. Outfit & furnishings can be a big cost driver too where there are large crews to accommodate. Accommodations costs have been increasing as ship design are expanding features for more crew comfort. In the U.S. more and more outfit work is being subcontracted, so these costs are becoming less of an issue in a more competitive market outside the shipyard. Modular accommodations components also can reduce costs, but do require a higher level of good engineering to be successful in reducing costs. Coatings are a large labor cost as indicated in Figure 7 below. Performing the majority of the blast and painting on blocks prior to erection (assumed by the Cost Model) can save sizeable labor hours and eliminate considerable staging costs. Applications of Radar Absorbent Materials (RAM) and Chemical Agent Resistant Coatings (CARC) are additional costs in this category.
7. Armament systems, for this particular demonstration, are negligible; these costs have largely not been included in this particular cost estimate. Nevertheless, armament (weapons) systems can be a significant cost driver for a military vessel.
8. Technical services for the Cost Model is relatively minimal and is set up to reflect only technical work to support change orders and the like. When using the Cost Model, all upfront (non-recurring) design and detail engineering is estimated and catalogued separately from the lead ship construction.
9. Shipyard services, in terms of labor hours, can be relatively high for a military vessel to accommodate more quality control and supervision efforts. Shipyard services can be of the order of 18% of total labor hours and go as high as 30% for military vessels.
10. The Cost Model does produce estimates for items such as bonds and insurance. It also includes any allocated percentages for margin or contingencies for the estimate. These costs, all outside the range of actual shipbuilding production costs (SWBS Group 10 added in the Cost Model), can be minimal, or they can be quite expensive.

SWBS 2-DIGIT LEVEL COST DRIVERS

The U.S. Naval Sea Systems Command produced a study on cost drivers. The following charts (Figures 2,3, and 4) show their study results for the three primary naval ship types: surface combatants, amphibious ships and auxiliary ships. While it must be assumed that these charts display ship type averages, what is not clear from these charts is how do they relate to the wide range of technologies employed by the designs within each of these three ship type selections.

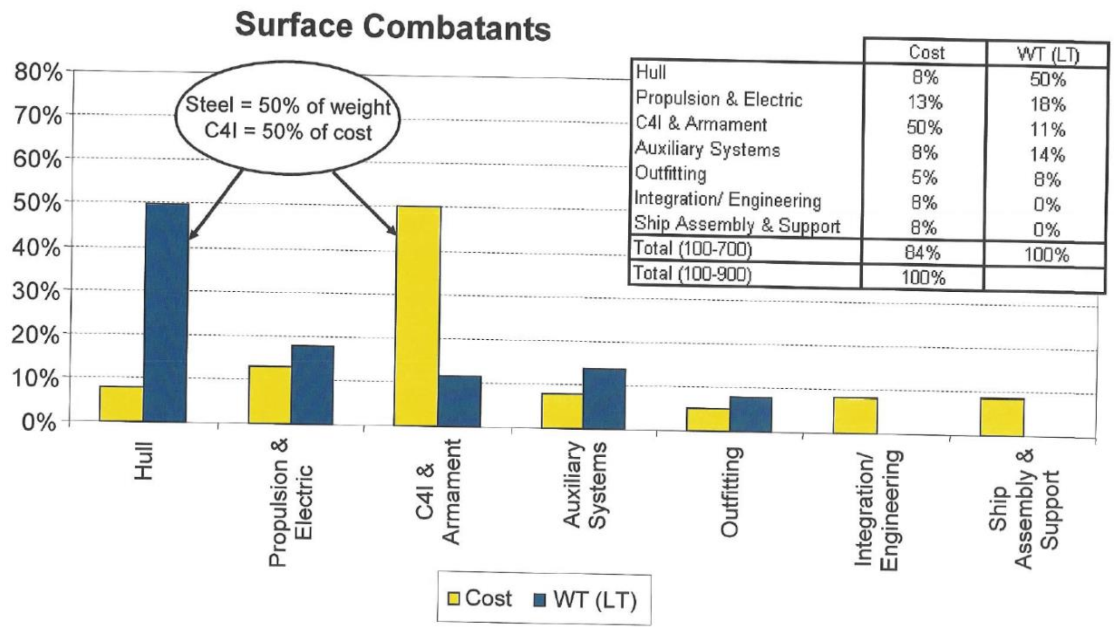


Figure 2: NAVSEA Cost Drivers for Surface Combatants

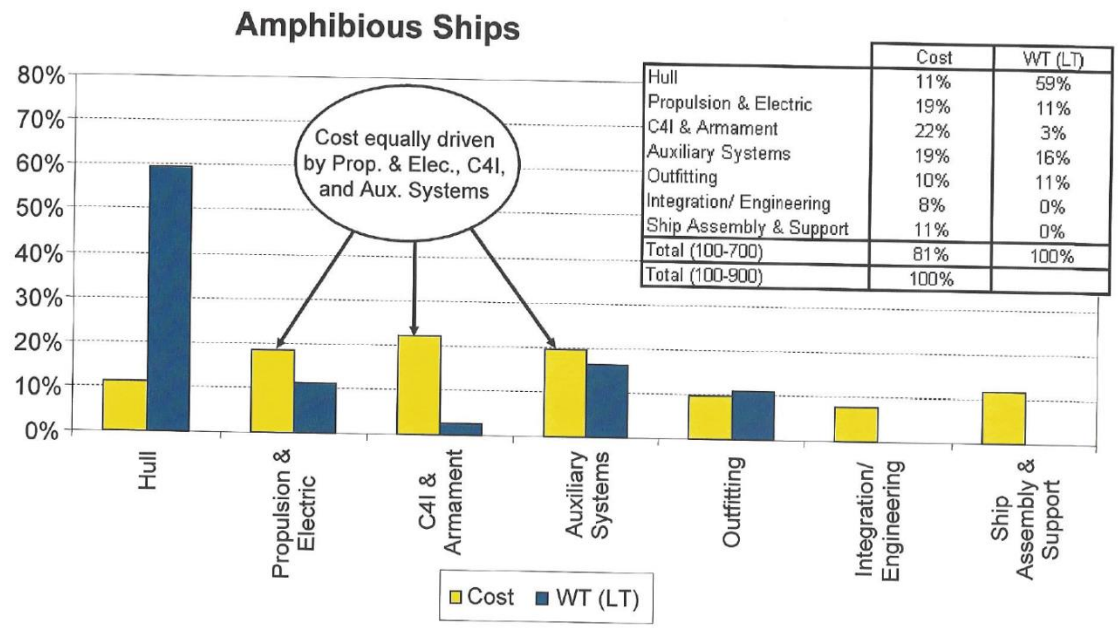


Figure 3: NAVSEA Cost Drivers for Amphibious Ships

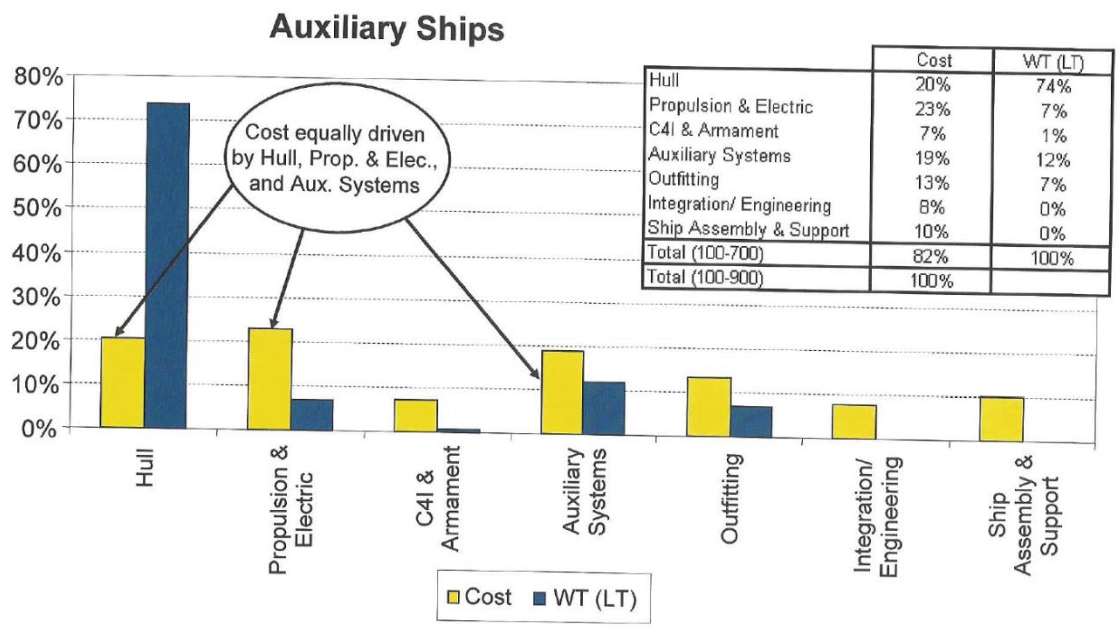


Figure 4: NAVSEA Cost Drivers for Auxiliary Ships

The Cost Model produces a similar chart (Figure 5a) for weight and cost drivers for the example offshore patrol vessel. It should not be surprising that when measuring these drivers for a specific ship design, the relationships of weight and cost between SWBS Groups can be considerably different from those indicated in the NAVSEA charts. For example, an averaging of hull weights of steel and aluminum vessels will result in a meaningless conclusion. Also not indicated is how costs that are incurred over an unspecified number of years make allowances for the effects of inflation. A necessary conclusion is that cost drivers need to be specific to the ship design at hand and of the build strategy anticipated to be used. In Figure 5a below, note that structures contribute over 41% of the weight, but only a little over 4% of the total lead ship cost. If the Cost Model sample had been configured with a full suite of C4ISR electronic and weapons systems, the proportion of the structural costs would be even smaller. This effect does not support the more common NAVSEA ship design philosophy that says bigger ships weight more and therefore cost more. Current advanced ship design concepts from both Europe and the Far East instead recognize that the larger size of ship and compartment volumes help reduce outfit costs and later operating and maintenance costs by virtue of easier access to systems, machinery and components.

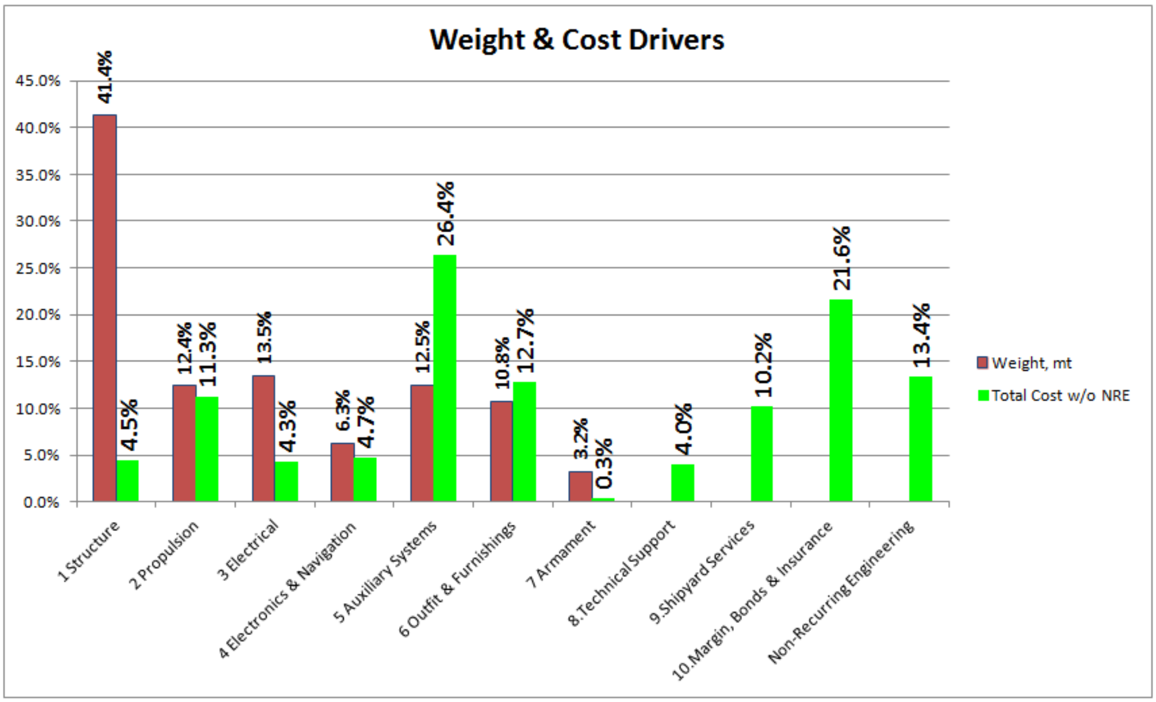


Figure 5a: SPAR Cost Model Reported Weight & Cost Drivers for a Sample Patrol Vessel

Figure 5b below illustrates weight and cost drivers for an example Ro-Ro vessel. The chart exemplifies a much less complex ship design than is a naval vessel. Note that the structural costs are significantly greater (34.9% versus 4.5%) than for a highly outfitted the patrol vessel.

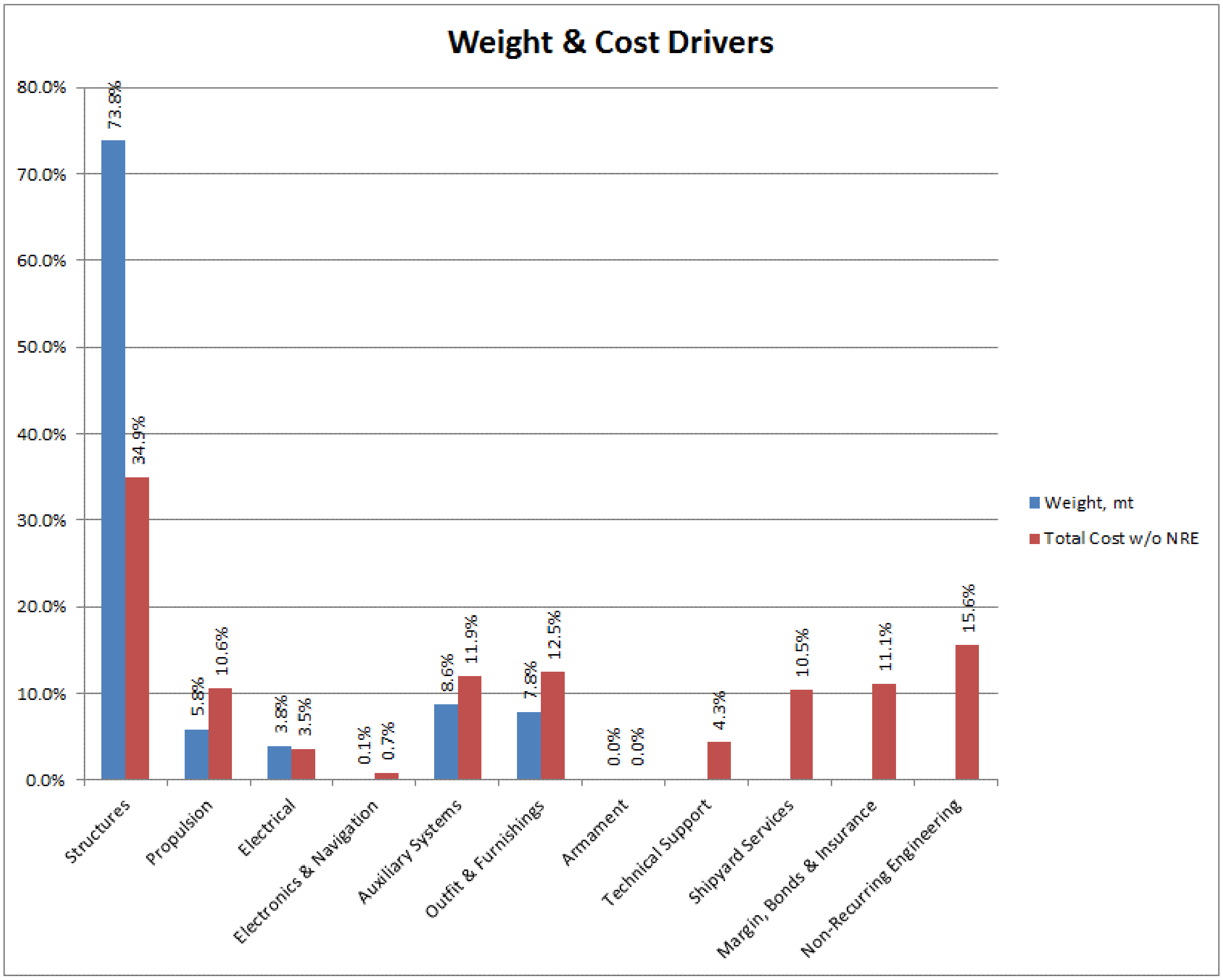
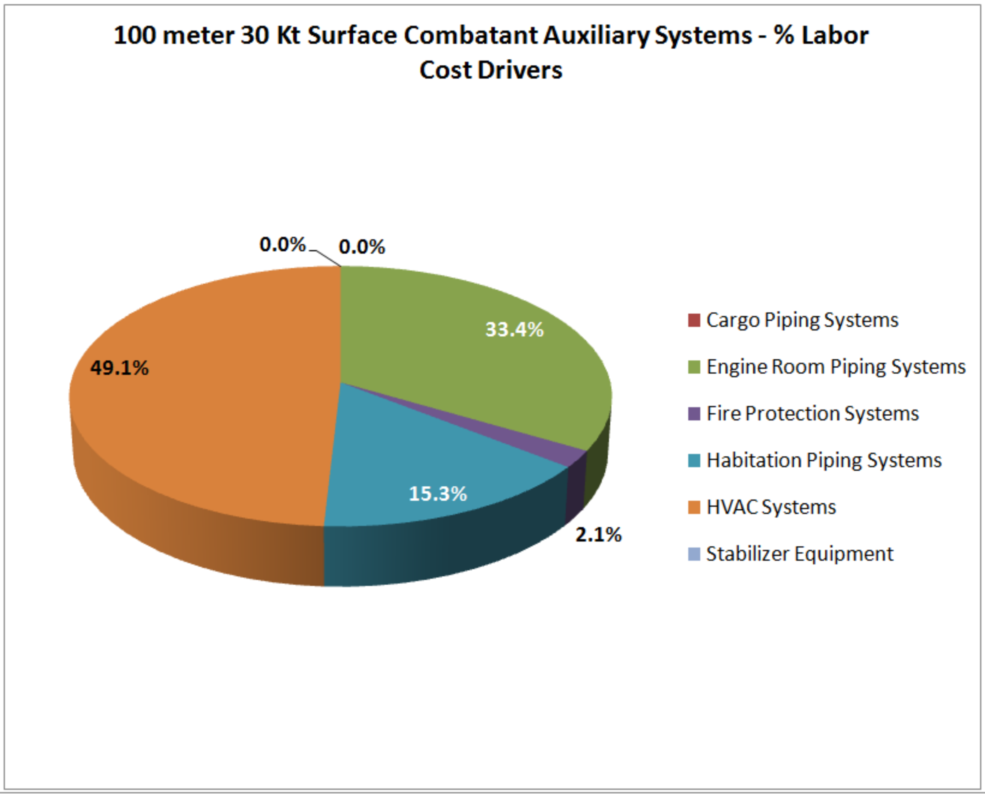


Figure 5b: SPAR Cost Model Reported Weight & Cost Drivers for a Sample Ro-Ro Vessel

SWBS 3-DIGIT LEVEL COST DRIVERS

While identifying high level assessments of cost drivers as described above is important, inspections of lower level cost drivers also is well worth the effort. The following takes a closer look at cost drivers in lower levels of the contract work breakdown structure - specifically, auxiliary and outfit systems, Figure 6 and 7.



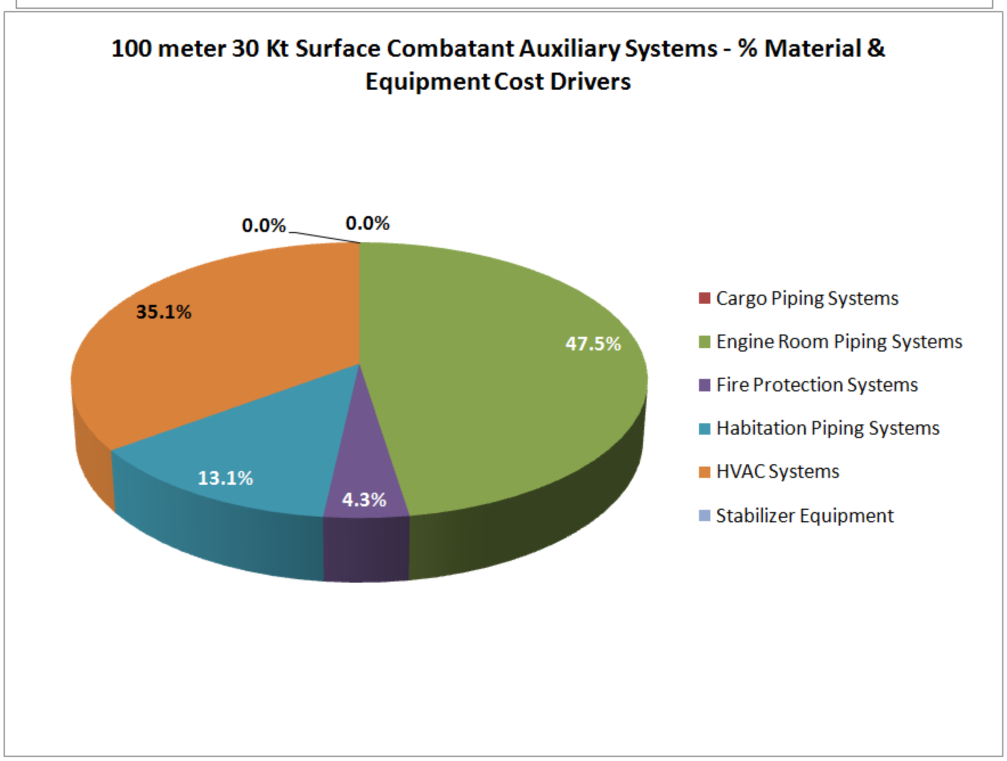
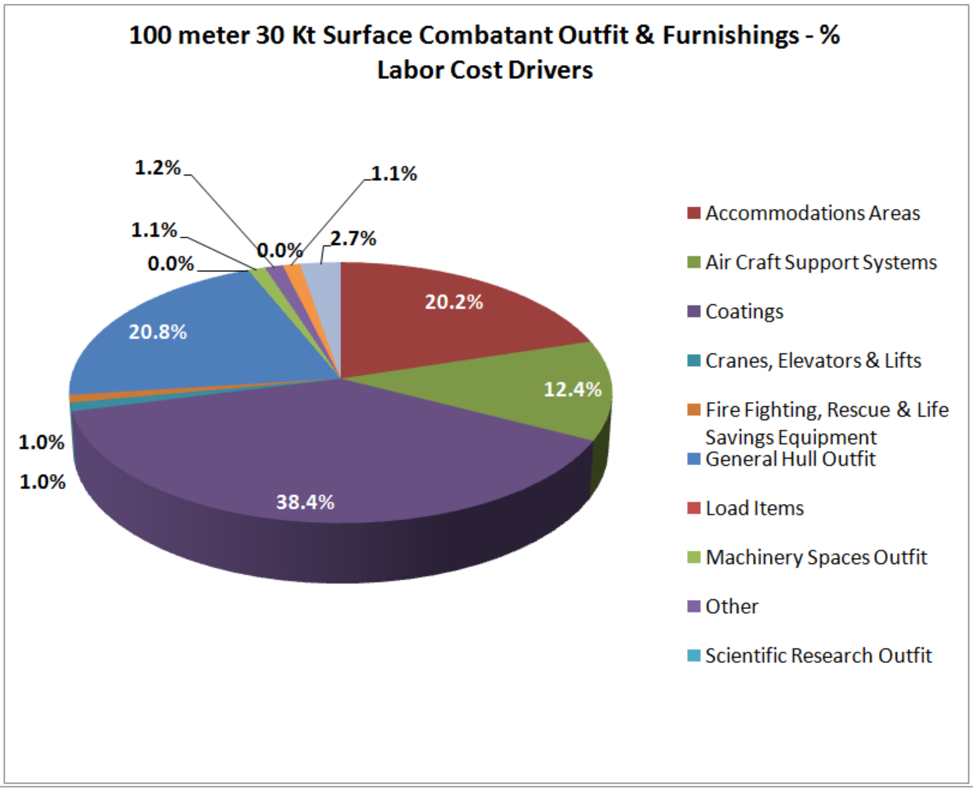


Figure 6: Summary of Labor Hours & Material Costs for Auxiliary Systems



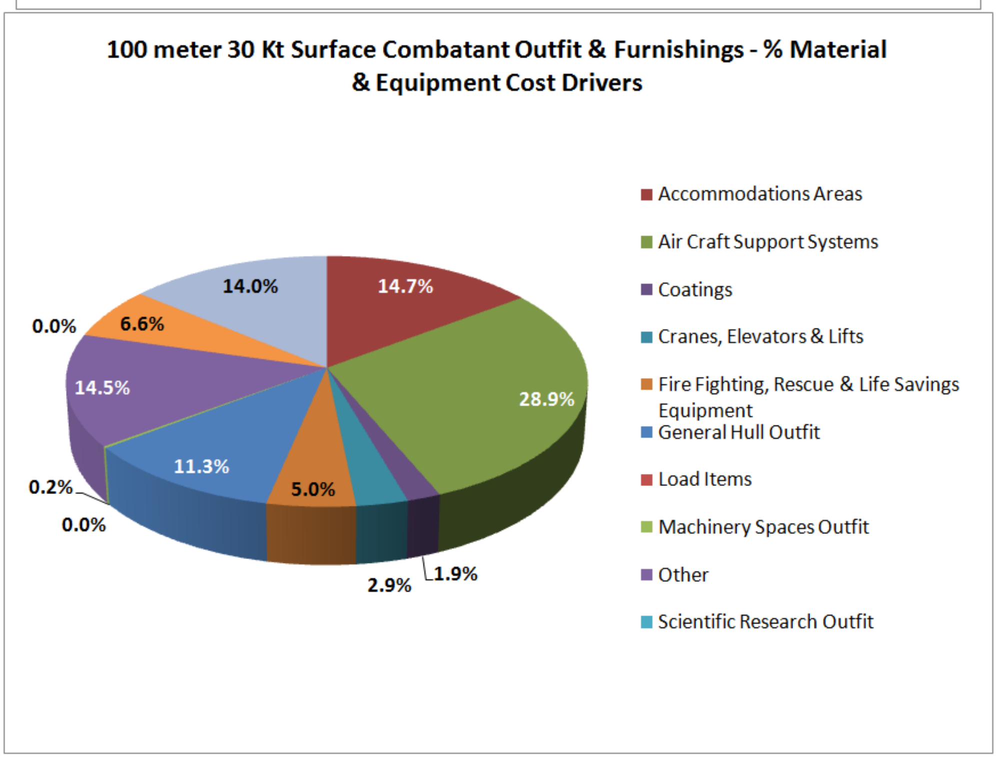


Figure 7: Summary of Labor Hours & Material Costs for Outfit & Furnishings

By proceeding further down into the details of the estimate, more insight can be gained as to whether or not the estimate is truly reasonable or not.

THE LESS VISIBLE COST DRIVERS:

Most recognize cost drivers as being the costlier equipment and systems of the ship design. These may be considered "hard" cost drivers. There also are "soft" cost drivers that are less easily identified and quantified. These soft cost drivers can become the dominant cost drivers, if not at the beginning of a contract, then often later and can make or break a successful contract.

1. <u>Outfit Density</u>: Labor costs will be higher if the relative volume density of outfit systems and equipment is higher. It means cramming the work space with components that restrict workers clear access to their work. High volume compartment densities further make ship operations in these confined spaces more difficult. With more difficulty, there is a higher price to pay. Labor hours for a highly packed naval ship can increase by 70%-80% compared to a low density volume of a tanker or bulk carrier. Volume density, then, can be a major cost driver, but is less visible from a traditional work breakdown structure point of view.

   SPAR evaluated relative outfit density from a selection of ships, commercial and naval (Figure 8) using the following formula:

   Density Factor = ∑(SWBS 200-700 MTON weights)/Ship M^3 Displacement.

   This factor attempts to measure outfit density within the confines of the ship envelop as measured by the ship displacement. 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 production efficiency
   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 8 displays density factors as computed for various ships, both commercial and naval:

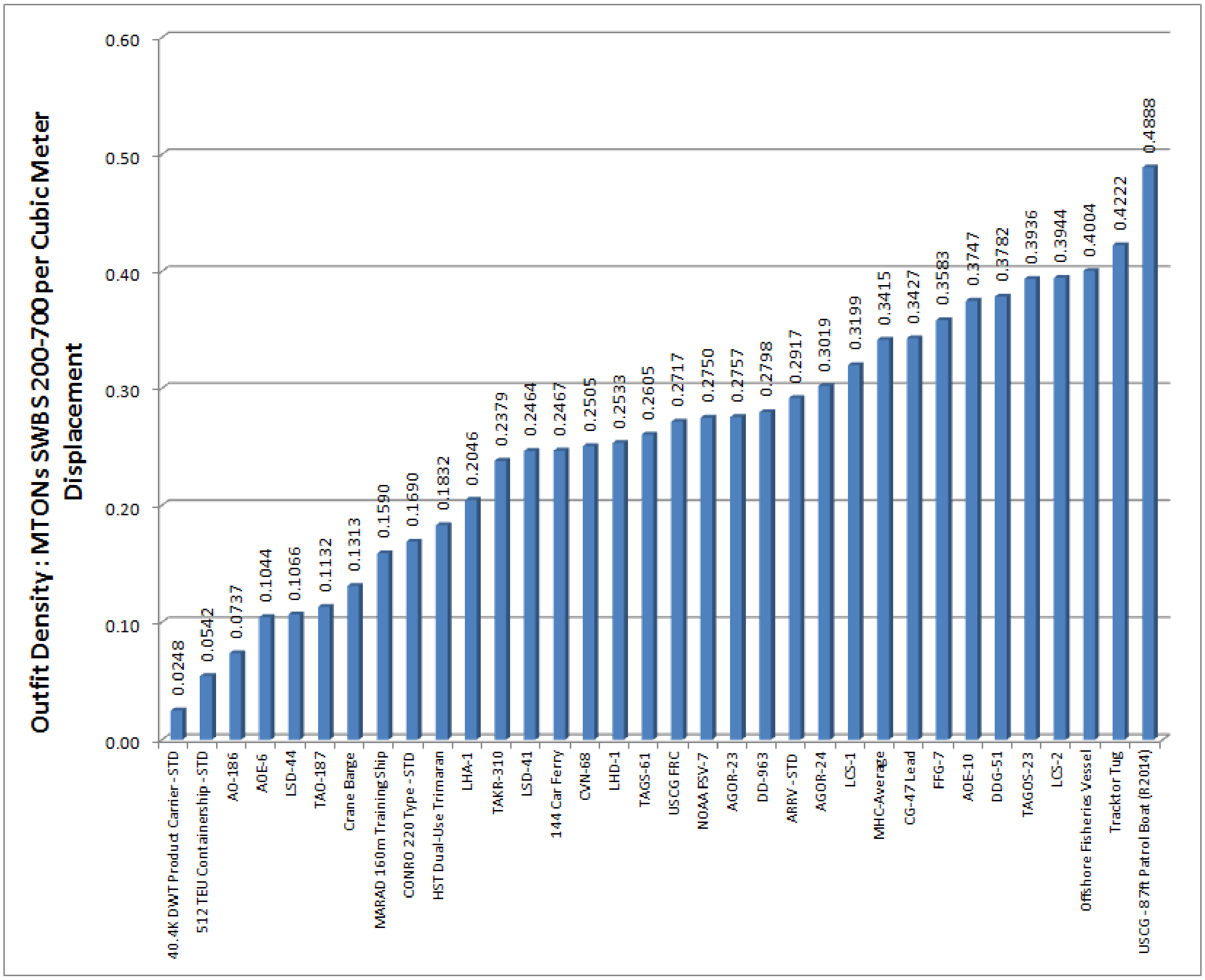


Figure 8: Density Factors for Various Ship Types

SPAR performed an outfit density/labor cost study that reviewed a very large mix of return costs involving different degrees of the above listed factors that affect return costs.

To correlate labor costs against density, there are a number of factors that need to be taken into consideration. Actual labor costs are dependent on a number of variables:

1. Specific Design Rules
2. Quality Assurance & Oversight Requirements
3. Extent of Early Stage Construction Savings

4. Quality & Maturity of Production Planning & Engineering
5. Competence & Incisiveness of Informed Management
6. Degree Change Orders Affect Budgets & Schedule
7. Skills & Discipline of The Work Force

What resulted was an apparent trend that supports the concept that labor costs do increase with the increase in outfit density.

The following Figure 9 illustrates a general relationship of actual outfit labor hours for different levels of outfit density.

The cost spread is due to the different design, engineering, production & management conditions that have affected the return costs as noted above.

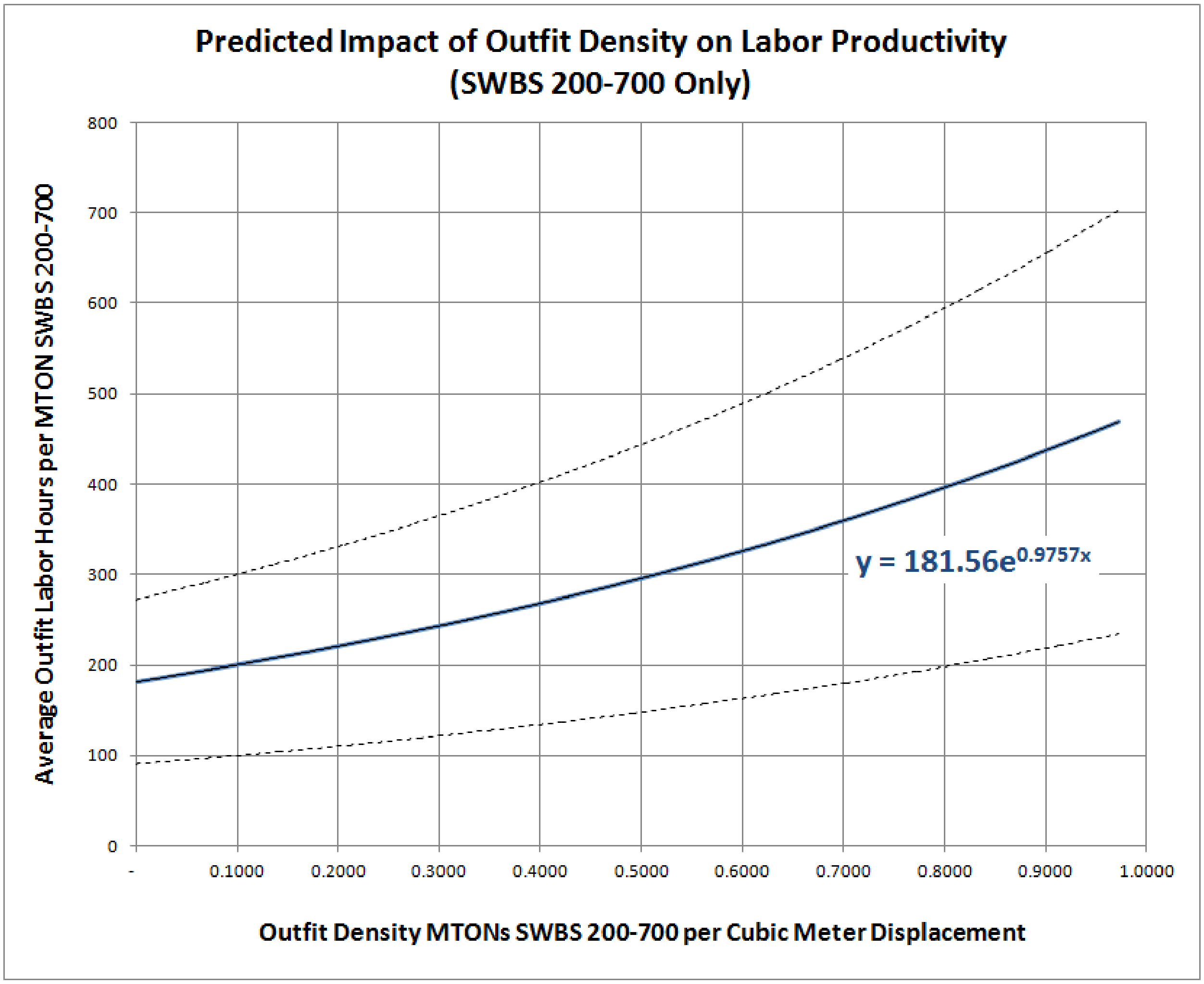


Figure 9: Labor Hours per MTON versus Density Factors

Figure 10 displays relative labor hour productivity as a function of the outfit density. This formula uses large volume, low density ship designs like tankers and bulk carriers for a factor of 1.0. The labor productivity factor then increases exponentially as the density increases.

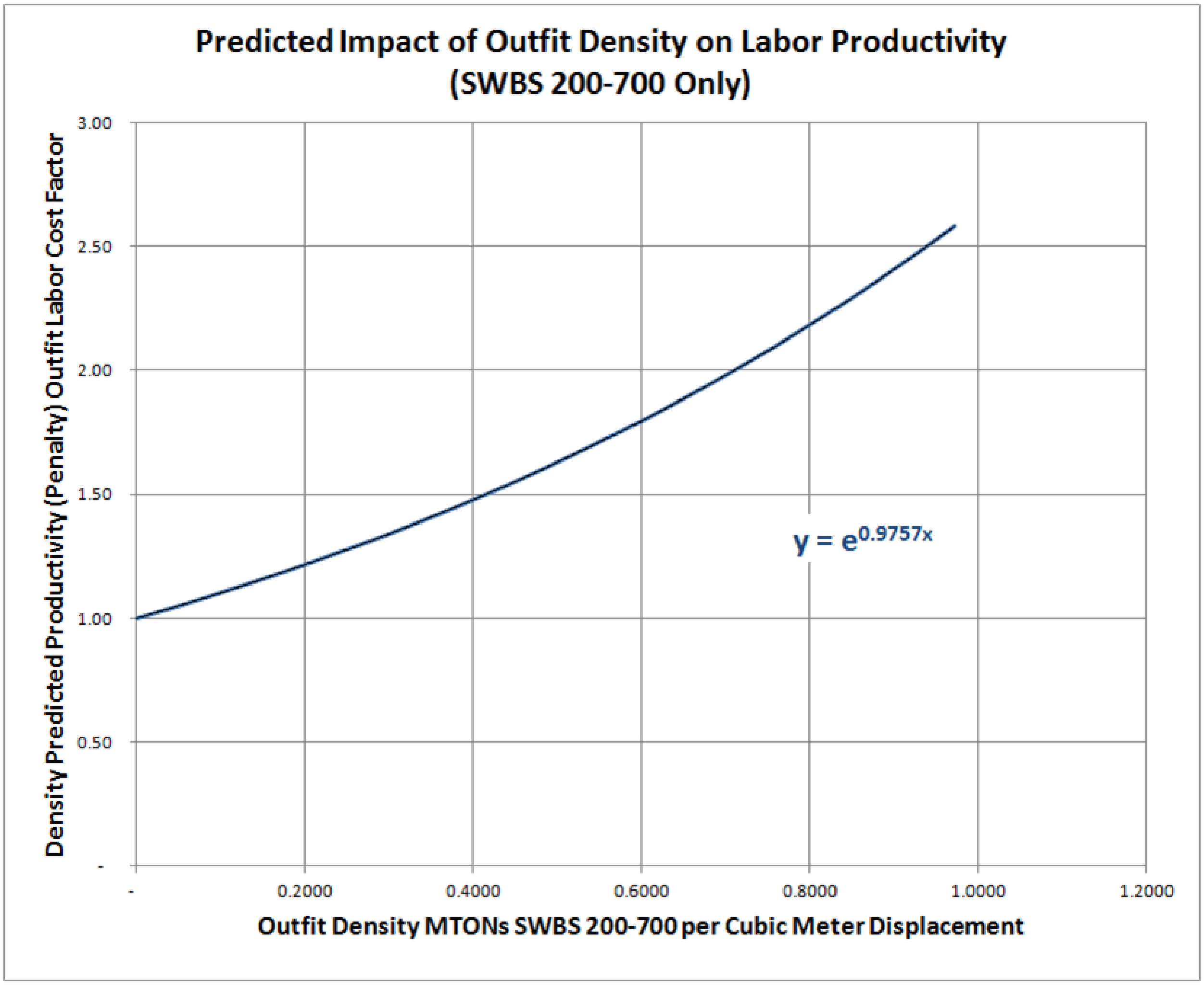


Figure 10: Predicted Impact of Outfit Density on Labor Productivity.

For the sample offshore patrol vessel, the Cost Model uses its displacement of 2,240 m3, its light ship weight of 1,387 mt (excluding structure) to determine an outfit density of 0.6191 mt/m3. The Cost Model then develops from this a density factor that estimates outfit productivity of 1.8296. This factor indicates that the labor hour estimate is predicted to be over 82% more to install outfit systems, machinery and components than if the open ship volume were more like that of a large product tanker or equivalent. This means that there is a labor penalty of 605,493 labor hours due to the high density of outfit and more difficult access to its installation efforts (Figure 11). Note that the estimated cost risk for production hours is also indicated. Figure 12 shows this penalty is over 24% of the total estimated Should Cost hours. This is no mean penalty to pay and needs to be recognized as a major design cost driver for the ship construction program.

Within limits, increasing hull length and increasing hydrodynamic efficiency can either increase potential speed for the same propulsion power or reduce the size and power of the propulsion plant and still maintain design speed. The latter is exactly what has been reported by one European shipbuilder to improve its competitive bid price.

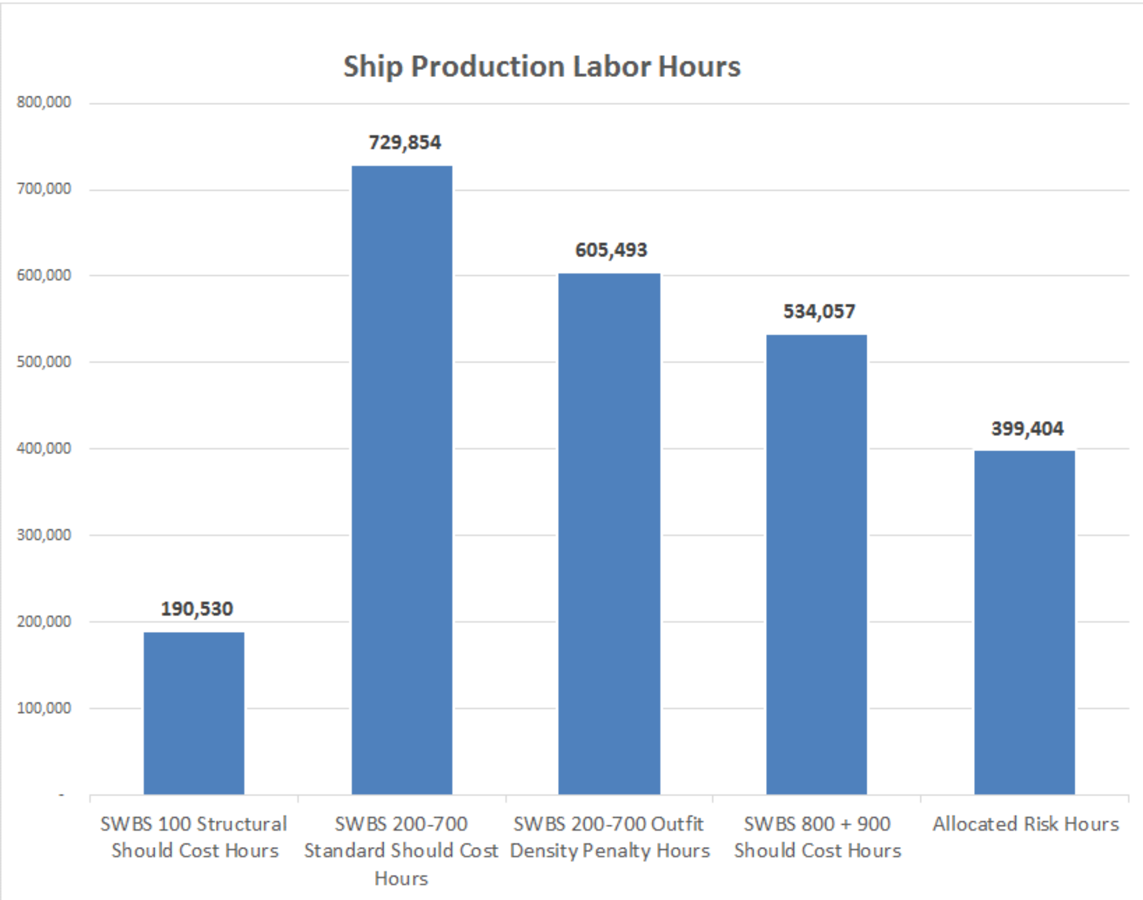


Figure 11: Breaking Out Standard Should Cost and Outfit Density Penalty Cost Labor Hours

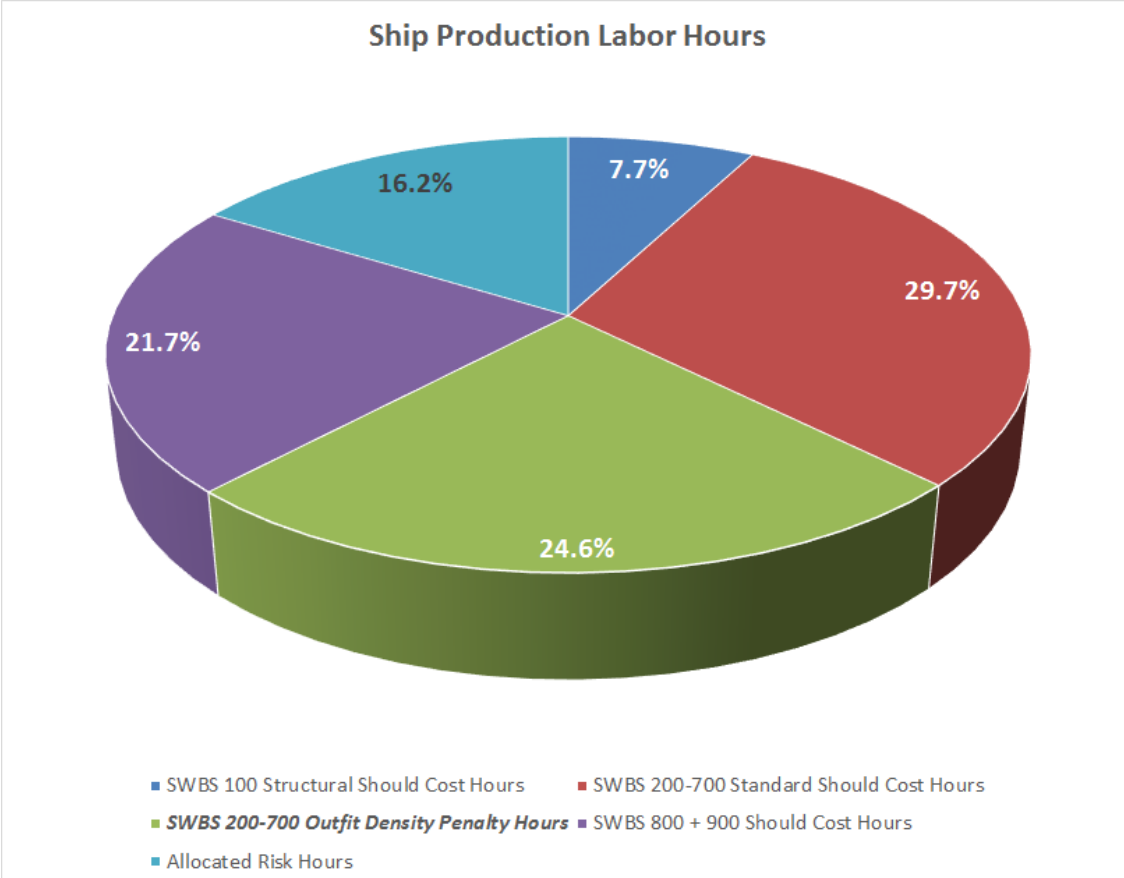


Figure 12: Breaking Out Standard Should Cost and Outfit Density Penalty Cost Labor Hours in Percentages

These density factors correlate well with earlier studies identifying outfit productivity differences between combatant ship builders and commercial ship builders, foreign and domestic. These factors also correlate reasonably well with studies developing cost differences of various ship designs using indexes of compensated gross tons (CGT). The use of density factors has produced cost estimates that correlate very well with actual shipyard bid prices across a variety of ship types.

There is, of course, a limit to where increasing displacement volume increases costs beyond outfit labor cost savings. Besides more hull structures, several outfit systems such as insulation and coatings and several auxiliary systems such as fire and wash will likely become costlier as the hull volume increases.

2. Quality & Timeliness of Engineering: A major cost driver is the quality and timeliness of the non-recurring design and engineering ("NRE"). If the technical information is late for production, production will need to do field engineering, which is fraught with more cost and high risk for rework. If technical information is late, production most likely will not be able to perform the work at the earliest and least expensive stages of

construction. A general rule of thumb is that work performed on block can take, on average, 3 times the labor hours than if the work were performed in the shop. Work performed on board can take 5-7 times the hours than shop work. Therefore, exploiting early stage construction is a very big cost-savings factor.

As a percentage of production labor hours, NRE has varied from 30% to 100%. The ability of engineering to directly support and enhance producibility greatly affects production costs.

Figure 13 breaks out a sample non-recurring design, engineering and detail production planning effort. A good review of this breakout is important to ensure that the technical requirements of the bid can be met and will ensure that the production stages of the contract will be successful, both for cost and schedule. Unfortunately, there are too many examples where this technical effort fails because of budgets (estimates) that do not correlate with the actual needs to support the contract, or there is a lack of trained designers, engineers and/or good production planners or there is less than fully competent technical supervision and management oversight. Whatever shortfall occurs on the technical side of a contract always spills over to become a cost and schedule liability for the production side. Failure of the technical effort to produce technical information on time to meet production schedules will most likely result in costly production rework, delays, and an inability for production to perform its work at the more efficient early stages of construction. These effects, then, can lead to significant cost drivers for a contract.

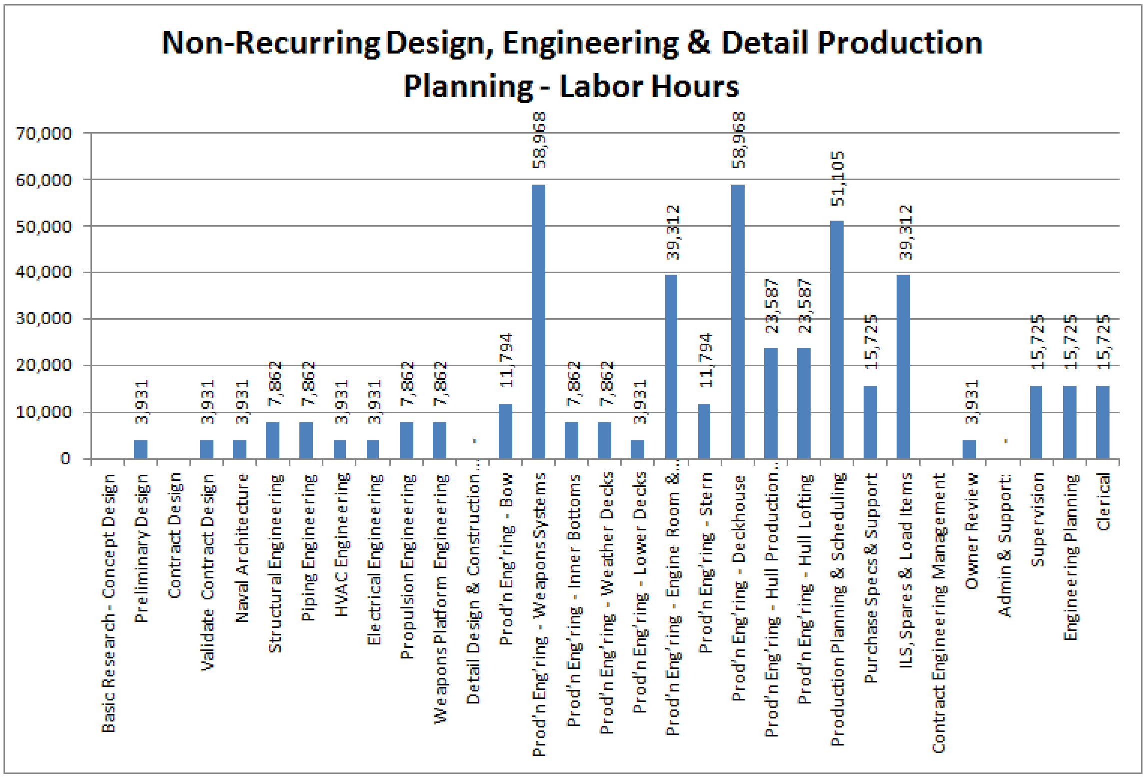


Figure 13: Sample Breakdown of Non-Recurring Design, Engineering and Detail Production Planning

3. Production & Shipyard Management Performance: Besides the engineering, there is the general performance of the shipbuilder, its planning and management oversight, which can have direct impact upon the costs and schedules. A poorly planned program invites major cost and schedule problems. When problems are visible (and they need to be), it is crucial how well and how quickly problems can be addressed and resolved before costs and schedules go critical. These added costs can be accommodated in the Cost Model via the structural and outfit productivity factors; they also can be accounted for via the Cost Model's cost risk assessments.

4. Cost Risk: Cost risk also needs to be considered as a potential cost driver for the final program cost and schedule. The Cost Model develops its cost risk assessments based on expected quality and timeliness of the engineering and expected performance of the shipbuilder. Low marks on either increases the estimate of "more likely cost" above the "should cost." Cost risk is often a major cost driver. In order to minimize these cost risks, specific attention should be focused on improving both the technical and shipyard production performance.

   Figure 14 illustrates this cost risk of production labor hours broken down into the five major risk categories processed by the Cost Model.

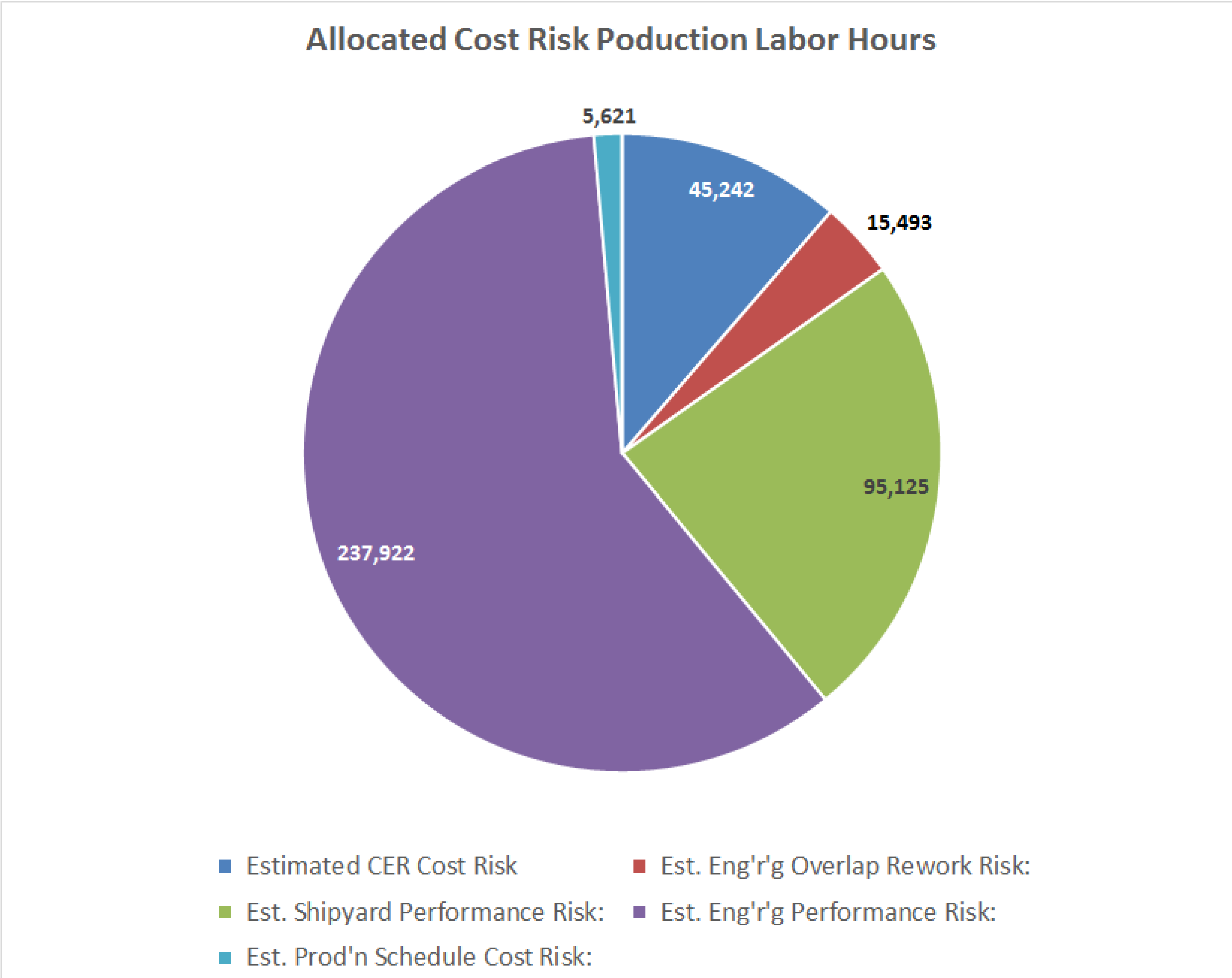


Figure 14: Breaking Out Production Labor Areas of Cost Risk

These cost risk assessments are potentially added costs to the "Should Costs" estimated by the Cost Model. In this example, engineering performance risk poses the greatest cost risk to the program. A special focus needs to be made to minimizes these specific areas of cost risk.

5. Change Orders: Finally, change orders made in the middle of production can carry heavy cost and schedule penalties. Change orders become important cost drivers that may not be readily and easily apparent during the earlier stages of design and engineering.

CONCLUSIONS

To be able to evaluate cost drivers, one needs to be able to identify them and understand their full relevance to a ship design and construction program. Since cost drivers often impact multiple issues, they need to be understood as early as possible in the design process. For example, if a naval ship requires more space on its mast to support a larger radar system, this relatively small change may result in a significant change if it adversely affects ship stability. Therefore, it is imperative that all major cost drivers and their risks be clearly identified and managed as early as possible.

The very least that an estimating cost model can provide is a thorough listing of the cost drivers so that they are readily visible for review and attention.

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