Estimating the Cost of Naval Ships

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Introduction

Defence procurement costs are in the news regularly. While new naval ships have not been in the spotlight as much as the F35 recently, they are not immune from the challenges of estimating the cost of procurement. The government tabled documents in the House of Commons on 8 May 2012 which indicated that the delivery of the Arctic Offshore Patrol Ships has been pushed back to 2018 and the cost of the estimated $3.1 billion project has already risen by $40 million. The Arctic ships are not the only ship acquisition project to make the news. In 2009 the government halted the procurement of the Joint Support Ships (JSS) when responses to the request for proposals made it clear that the $2.9 billion allocated for the program was not sufficient. Peter Cairns, President of the Shipbuilding Association of Canada, stated that the government's budget for shipbuilding projects has been unrealistic for the capability desired.[1]

How hard is it to estimate the cost of a new naval ship? As most professionals involved in ship acquisition will tell you, estimating costs is fraught with risk and uncertainty, and it is a skill not widely understood. Now that Canada is entering a period of sustained fleet renewal for the Royal Canadian Navy, it is important that all those involved in the discussion of the future fleet – academics, journalists, politicians and the public – understand the complexity of estimating the cost of a naval ship.

Any discussion on the future navy must consider two questions:

- What is the required capability?
- What will it cost?

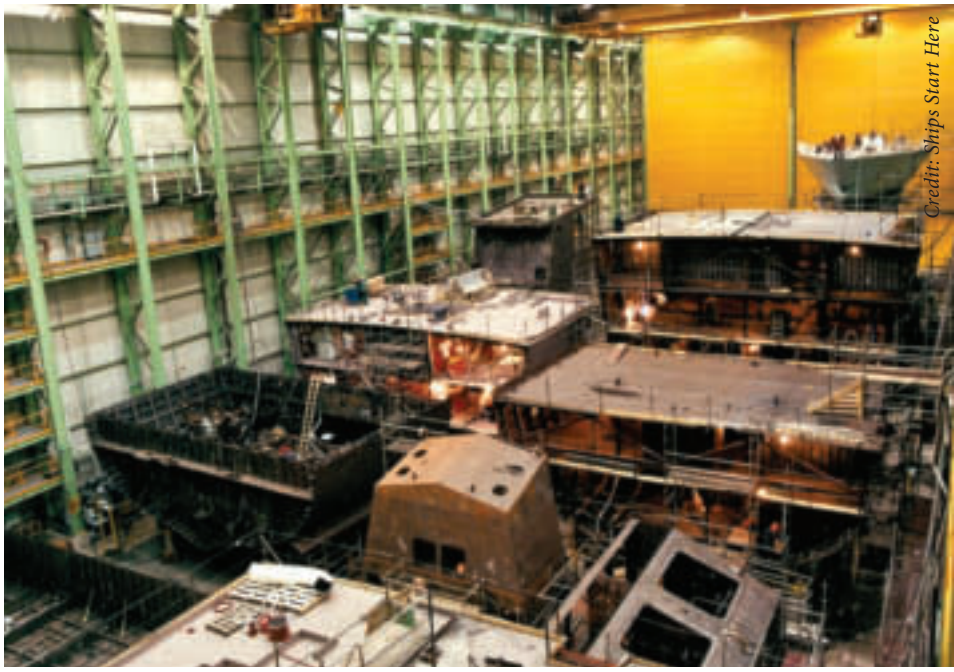
In the Canadian context, the cost of a ship project is fixed very early in the process which makes estimation of the cost to design and build the ship one of the key early tasks. Before any detailed information is known, the government must know how much money to set aside to acquire a ship and whether that amount represents good value. The government has an obligation to taxpayers to ensure that military equipment whether for the land, the sea, or the air is purchased at the right price, at the right time and with the right capability. The cost-estimating challenge is to understand how cost and capability are related and then to use that knowledge to guide decisions to acquire the right ships for the requirement.

Naval ships are unique. No other piece of defence materiel is so complicated and is designed and built in so few numbers to unique requirements. Consider Canadian ships, they are able to serve worldwide from the Equator to the Arctic because distinctive requirements exist for Canada's three-ocean navy.

The Cost-Capability Challenge

Before embarking on any procurement project, the government's first steps are establishing the capability of the equipment desired and, most important to taxpayers, establishing the maximum cost. In the end, the government must decide what Canada is willing to pay for military capability.

When the government announces a new military project and the cost for it, that cost becomes a not-to-be exceeded boundary for the project. The dilemma then is predicting a budget within which a contractor can find an acceptable design solution for government. Setting budgets for projects is not done lightly. Unfortunately, budgetary costs must be set very early in the ship acquisition process when only capability requirements and design concepts are available. The government must become familiar with what a warship should cost. It has no excuse for not doing this – the government must be an informed purchaser. However, this is more challenging than it seems. The design and build of naval ships one of the most complex engineering endeavours since a naval ship is a system of systems, the integration of which usually involves many



Credit: Ships Start Here

A frigate under construction at Irving Shipbuilding in Saint John, New Brunswick.

designers, engineers and technicians from a variety of companies and equipment manufacturers.

Becoming informed involves a series of investigative studies and concept designs intended to explore the cost-capability relationship of purpose-built and military off-the-shelf (MOTS) designs. This early work is challenging because it must be done by the Department of National Defence (DND) without consulting industry. Design solutions from shipbuilders that come with costs are not readily available, and would take millions of dollars to develop. In any case, it is not a realistic approach because part of the exercise is determining the capability the country can afford before engaging any suppliers. The goal is to establish a cost ceiling for a project that will permit an acceptable design solution. If the estimate is low, then capability tradeoffs become necessary. If the cost estimate is too low, then an acceptable design solution becomes impossible because the desired capability is simply unaffordable.

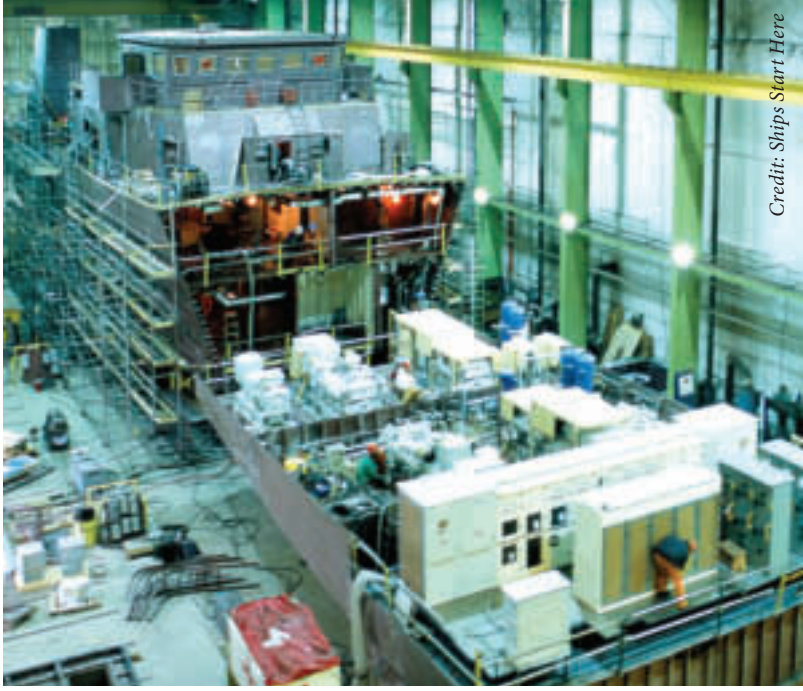
Cost Models and Design Tradeoffs

Early and accurate estimates of the cost of a ship are very important – this is a paradox because early estimates are rarely accurate. If early cost estimates are too low and the budget the government allocates for a project is insufficient, the problem may not become apparent until suppliers respond with proposals. This not only wastes time, it places the procurement in jeopardy because it is not easy to reallocate money between projects

Initial cost estimates for a purpose-designed ship typically quote an error of ±40%, so the risk of under- or over-predicting cost with early estimates is significant. Over-predicting cost is problematic because equipment acquisition is planned for years, and over-predicting diverts financial resources from other important projects. Yet no project can proceed without an indication of cost so the estimate risk must be accepted and managed. The risk is that cost is underestimated and the procurement process fails.

Most of the work supporting the cost estimate of a purpose-designed ship is done using concept designs that explore a series of solutions that might be acceptable. This exploration allows examination of capability and various design tradeoffs to give a variety of different options. Each option must have an associated cost. This early stage examination of design capability and cost is critically important because decisions are made that will set the basic architecture of the ship and ship systems, which affect both construction and through-life cost.

The traditional early cost-estimating tool used for this work assumes that the weight and the cost of various systems and equipment are linked. Weight is the most



Credit: Ships Start Here

Maritime Coastal Defence Vessel under construction at Halifax Shipyard.

convenient attribute upon which an initial design cost may be based because it can be easily scaled and adjusted for different ship sizes, even with limited design information. Historical information from a known design and cost data for selected major systems and equipment can provide first approximations of ship cost for a series of concept designs that meet the capability requirement.

Another reason that weight is such a useful indicator for cost is that weight data is also an important element of a ship design. Draft, trim, heel, stability, strength and sea keeping are just some of the ship characteristics that are affected by weight or influence weight. Weights are also easy to predict from existing ships because they will vary predictably with ship characteristics. The key is selecting the ship characteristics where strong correlation with weight exists. For example, the size and weight of a power plant and the minimum compartment length for an engine room are related to the propulsion type and the installed power. The weight of the pipes in a ship correlates well with ship length. The magic in predicting cost is developing the Cost Estimating Relationship (CER) that links a weight to cost. Different CERs are used for different weight groups. When all the weight groups are added together, it gives the weight of a ship. The designer can then use the costs from an existing ship of one size with one group of weights to predict the cost of a new ship of a different size and different weights. When precise costs are known – such as the cost of a propulsion engine, equipment or system – that cost can be directly included.

This approach to cost estimation is one of the simplest, but it is still time consuming. As well, getting good data to develop a model and the CERs is often difficult, particularly if current cost information is not available. More significantly, the weight-based system of cost estimation has one important limitation – weight-based cost models

cannot easily account for the cost of the *complexity* of a ship design.

Getting good data for a cost model is difficult; getting recent *Canadian* data is nearly impossible. In the 1990s DND's Chief of Review Services (CRS) explored the comparable costs of ships from other states in a review of the cost and capability of the Canadian Patrol Frigate (CPF) project and noted how difficult costs were to determine. This experience highlighted the challenge of getting accurate information on costs. For one thing, shipyards do not release production cost data, and an added complication today is that Canada has not built major warships since the CPFs in the 1990s. At that time, CRS used data from *Jane's Fighting Ships* and *Forecast International* to predict the cost of comparable warships but noted that the information was not sufficient to support hard conclusions on the relative performance and cost of the ships.[2]

Credit: Ships Start Here

Maritime Coastal Defence Vessel ***Edmonton*** *under construction at Halifax Shipyard in 1996.*

Cost estimation based on weight can provide data on the design and build of a ship, but it is not a reliable way to estimate all project costs. What is considered in project costs can be controversial, as the debate on the F35 cost figures shows. The life-cycle costs of operating and maintaining a ship for its design life must also be estimated to determine total cost. The US Navy's Naval Sea Systems Command (NAVSEA) life-cycle cost data shows that on average, over a 25-year life, the cost of operation and maintenance is almost double the cost of acquisition.[3] One would expect a similar or higher ratio for the RCN since Canada typically operates ships for 30 to 40 years.

Challenges with the Cost-Estimating Process

The government's ability to estimate ship cost will never be perfect, no matter which method is used as long as the acquisition process is competitive. In the interest of fairness and impartiality, the acquisition process effectively places a wall between those setting requirements and those developing solutions. The competitive acquisition process has an underlying ideology that this process "unleashes creativity that can solve virtually all problems."[4] But competition in a restricted marketplace makes it hard to estimate cost. Norman Friedman, a noted US naval historian, has argued that a competitive process for warship acquisition has a profound effect on the ability to predict cost for both the government and the bidder.[5] Unfortunately, for the bidders it creates problems because:

- the scope for creative and innovative cost-saving solutions is often very limited; and
- bidders assume significant risk if forced to bid on flawed requirements, which drives up costs. The alternative is to refuse to bid or to submit a non-compliant bid.

The process can raise problems for government as well because:

- the implication of flawed requirements only become clear when the bids arrive with costs higher than expected;
- if problems occur once a contract has been written, it is extremely expensive to backtrack on any of the requirements in order to reduce costs; and
- if contract terms are badly written, the builders may deliver an unexpected solution that cannot be compared with other solutions for technical merit or cost.[6]

Friedman used the example of the USN's DDG-1000 to illustrate an important point about problems with ship requirements. The *Zumwalt*-class was supposed to be the cheap, disposable ship for the future. The problem, Friedman points out, was that the USN did not seem to realize that the stealth requirements placed on the class would drive the cheap, disposable ship to three times the size of a CPF or result in a hull form that needed active stabilization because it no longer had stability in all conditions.[7]

The USN experience is not unique. We have our own Canadian example, the Joint Support Ship (JSS). The JSS project was intended to deliver three multi-mission highly capable ships. The government announced the project in 2004 timed to replace the navy's aging fleet of replenishment vessels. The government terminated the competitive procurement process in 2008 because the design solution for the ship's capability requirements could not be found within the allocated budget.

The Canadian government has a National Shipbuilding Procurement Strategy (NSPS) that is designed to counter some of the costing challenges posed by the competitive process. The NSPS used a staged competitive process to engage and select shipbuilders early, before design even

engage and select shipbuilders early, before design even commenced in many cases, thus creating an environment in which discussions can occur between those setting capability requirements in the government and those responsible for developing the design solution in industry. Nevertheless, limitations in cost estimating will still occur because capability requirements and associated budgets are set before contractors are engaged to determine the solution.

The biggest limitation in Canada right now is lack of reliable data for weight and cost relationships. We have not built any frigates since the 1990s. The last time Canada built a supply ship was the 1960s. DND cost estimators do not have good data from contractors. As a result, estimators use cost and weight relationships derived from other documents or sources – thus they are estimates of estimates. Almost no feedback is possible to correct major errors in cost, at least until after the budgetary limits are set and responses are received from contractors. Recent and relevant data are just not available for cost estimation in Canada.

Accounting for design complexity is important. Recent US trends in naval shipbuilding have shown a steady increase in the complexity of warships. This leads to higher costs because complexity requires more design effort and construction hours. The influence of complexity is seen in the cost per ton difference for different ship types and in the variance within the ship type. Ships that are more complex cost more per ton. This means that cost estimation should include consideration of both weight *and* complexity, and cost estimations should not be derived from just looking at ships of similar weight but also ships of similar complexity.

The huge difference in cost per ton between naval and commercial ships occurs for several reasons. Unlike commercial ships which function with relatively small crews, naval ships dedicate significant space for large crews. As well, naval ships often have relatively large propulsion systems in small spaces, electrical and cooling systems must be capable of greater loads, and weapon and sensor systems must be carefully positioned. All electrically powered equipment and systems need power and control cables and cooling water, all of which compete for prime space sheltered from the effects of enemy weapons. This means that naval ship specifications are inevitably more numerous and complicated. Competition for space and location challenges the designer to optimize arrangements and carefully control the ship's centre of gravity.

Figure 1 illustrates in a simple graph the challenge of complexity by comparing the labour required to build a destroyer and a bulk carrier. Note the difference in labour hours that complexity requires.

Table 1.
Comparison of Costs Among Ship Types

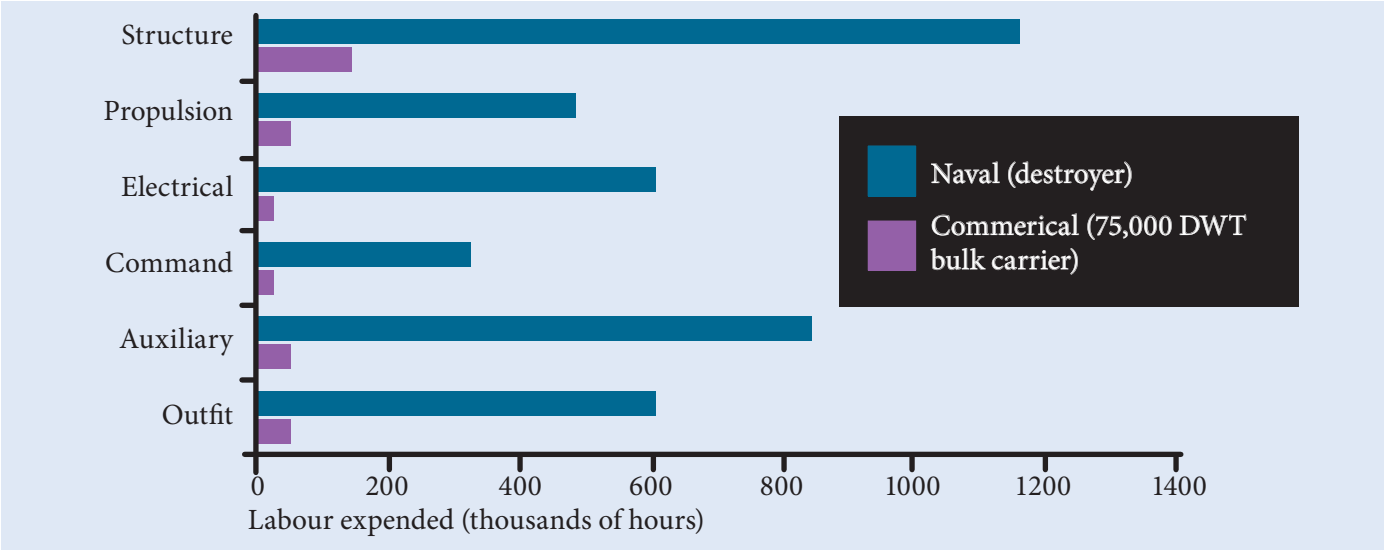
Ship Type	Average Light Ship Cost [$US/1000 Ton]
Conventional Submarine	103 to 347
Nuclear Submarine	185 to 250
Destroyer	122 to 168
Frigate or Corvette	70.8 to 217
Aircraft carrier	69.8 to 67.0
Cruise ship	10.0
US built crude oil tanker (medium)	6.93
Chemical product tanker (small)	2.84
Container ship	3.10
Crude oil tanker (medium)	2.20
Oil product tanker	1.63
Bulk carrier (small)	1.26
Bulk carrier (medium)	0.88

Source: John Birkler, et. al., "Differences Between Military and Commercial Shipbuilding: Implications for the United Kingdom's Ministry of Defence," RAND Report MG-236 (Santa Monica: RAND Corporation, 2005), statistics taken from Table 3-1, available at http://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG236.pdf.

Another challenge for cost estimating is the time involved in the acquisition process. The significant time that the process takes means decreased value of the budgeted amount and increased costs associated with inflation. Everyone is aware that military procurement can take a decade or longer between the announcement of a project and the signing of a contract. Over that time the value of money erodes, and the price of commodities changes. The time value of money is often ignored in the discussion, but every year a project budget sits unused, it buys less. A recent example of this is the JSS project. The project and its budget of $2.6 billion was first announced in 2004. The ships will now be built as part of the NSPS in the near future. Every year since 2004 inflation has reduced what the project budget can buy.

Assuming that the JSS contract is signed in 2014 and the government starts paying for the ships, that would be 10 years since the initial budget was established. Taking into account annual inflation rates since 2004 and an estimated annual rate of 2% for 2012 and 2013, a contract to build the JSS would require $3.83 billion in 2014 for the same capability that $2.6 billion would have bought in 2004. Since the JSS budget is fixed, $2.6 billion in 2014 will only

Figure 1. A Comparison of Labour Hours



Source: John Birkler, et. al., "Differences Between Military and Commercial Shipbuilding: Implications for the United Kingdom's Ministry of Defence," RAND Report MG-236 (Santa Monica: RAND Corporation, 2005), available at http://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG236.pdf.

buy Canada two-thirds of what that amount could have bought in 2004. Because of this, the design solution must sacrifice capability requirements to stay within budget which means that Canada will receive less capable ships and possibly fewer less capable ships. Practically, a two-thirds reduction in buying power will have a significant effect on the resulting design solution. Only when the design contract is announced will the actual reduction in buying power become apparent.

But inflation is not the only enemy. In the RAND monograph *Why Has the Cost of Navy Ships Risen*, the authors note that the cost growth trend in naval ship construction since the 1960s is twice the rate of inflation.[8] The additional increase above inflation was caused by 'requirements creep.' This phrase refers to the tendency over time of navies – and this applies to equipment purchases for the other branches of the armed forces as well – to replace older ships with more capable and more complicated ships. This often means that simple traditional tasks are now undertaken by extremely capable and expensive ships.

Conclusion

The expectations that cost estimates will be accurate are often unrealistically high because the difficulty of calculating accurate costs is not really understood. If costs rise, it can lead to the perception that costs are not well controlled when in fact cost estimates are just estimates continually being refined as cost-capability relationships are better understood. The government has made an important step with the NSPS to create relationships between government and industry that will improve the cost estimates of Canadian naval ships as shipyards on the East and West Coasts start building ships again. When actual cost data become available for cost models, estimates for future ship classes will become more accurate, alleviating some of the current challenge in predicting cost.

But even with more accurate data in the future, estimating the cost of building Canadian naval ships will be challenging! Budgets are just best estimates of the cost of a capability that are outlined early in a project. We must expect cost-capability tradeoffs to become necessary as more accurate costs become known. Design complexity is difficult to estimate when cost data comes from different ship types. Finally, even low inflation and the gradual increase of other costs can play havoc with any fixed budget given enough time.

Notes

1. Lee Berthiaume, "Armed Arctic Vessels Face Delay in Latest Procurement Setback" *Postmedia News*, 8 May 2012, available at www.canada.com/story_print.html?id=6588081.
2. Chief of Review Services, Department of National Defence, "Report on Canadian Patrol Frigate Cost and Capability Comparison," 7050-11-11 (CRS), 26 March 1999, available at http://dsp-psd.pwgsc.gc.ca/Collection/D2-127-1999E.pdf.
3. Fred Harris, "Total Ownership Cost (TOC)," Presentation at the American Society of Naval Engineers Day 2011, Arlington, Virginia, 10-11 February 2011, p. 3, available at www.navalengineers.org/SiteCollectionDocuments/2011%20Proceedings%20Documents/ASNE%20Day%202011/Presentations/Harris.pdf.
4. Norman Friedman, "How Not to Design a Warship," US Naval Institute *Proceedings*, Vol. 134, No. 7 (July 2008), available at www.usni.org/magazines/proceedings/2008-07/world-naval-developments.
5. *Ibid.*
6. *Ibid.*
7. *Ibid.*
8. Mark V. Arena, Irv Blickstein, Obaid Younossi and Clifford A. Grammich, *Why Has the Cost of Navy Ships Risen?* RAND Monograph 484 (Santa Monica, RAND Corporation, 2006), available at www.rand.org/content/dam/rand/pubs/monographs/2006/RAND_MG484.pdf.

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