Journal of Cost Analysis and Parametrics, 6:118–167, 2013

ISSN: 1941-658X print / 2160-4746 online
DOI: 10.1080/1941658X.2013.843423

www.iceaaonline.com

Feasibility of Budget for Acquisition of Two Joint Support Ships

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The mandate of the Parliamentary Budget Officer is to provide independent analysis to Parliament on the state of the nation's finances, the government's estimates, and trends in the Canadian economy, and, upon request from a committee or parliamentarian, to estimate the financial cost of any proposal for matters over which Parliament has jurisdiction. The PBO received requests from the Member from St John's East and the Member from Scarborough-Guildwood to undertake an independent cost assessment of the Joint Support Ship project. This report assesses the feasibility of replacing Canada's current Auxiliary Oiler Replenishment ships with two Joint Support Ships within the allocated funding envelope. The cost estimates and observations presented in this report represent a preliminary set of data for discussion and may change subject to the provision of detailed financial and non-financial data to the Parliamentary Budget Officer by the Department of National Defence, Public Works, and Government Services Canada, and the shipyards. The cost estimates included reflect a point-in-time set of observations based on limited and high-level data obtained from a variety of sources. These high-level cost estimates and observations are neither to be viewed as conclusions in relation to the policy merits of the legislation nor as a view to future costs.

Executive Summary

Précis

In 2004, the Government of Canada announced that it would replace the Royal Canadian Navy's Protecteur-class Auxiliary Oiler Replenishment (AOR) ships. Three Joint Support Ships (JSS) were proposed, with a contract to be awarded in 2008, the first ship delivered in 2012, and the project completed in 2016 (Treasury Board of Canada Secretariat, 2008). The Government allocated $2.1 billion to design, develop, and acquire the three ships (Gilmour, 2005).

In 2009, however, the Government found that the three ships would not fit within the $2.1 billion budget. In response, the number of ships was reduced to two, delivery dates pushed out, and requirements changed (National Defence and the Canadian Forces, 2011).

The new budget was set at $2.60 billion in fixed nominal dollars (National Defence and the Canadian Forces, 2010). This means that the Government plans to make $2.60 billion available to design and build the ship, with no further adjustments for inflation.

Members for St John's East and Scarborough-Guildwood requested the PBO assess the sufficiency of the JSS's $2.60 billion budget. The PBO developed a parametric cost model for this purpose. As the final characteristics of the JSS are not entirely clear, the PBO estimated the cost of replacing the current Protecteur AORs with two analogous ships

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TABLE 1 Comparison of DND and PBO estimates and budgets for protecteur replacement

	DND	PBO
Estimate	$2.53 billion	$3.28 billion
Budget	$2.60 billion	$4.13 billion

Sources: National Defence and Canadian Forces, *supra* note 4; DND estimate from "JSS Historical Options Analysis Costing Brief to PBO," June 12, 2012.[1]

built according to Government procurement rules in Canada. All figures in this report are presented in nominal fixed dollars.

As shown in Table 1, DND estimates that replacing the Protecteur will cost about $2.53 billion, and the budget set aside is about $2.60 billion. The PBO's model suggests that these amounts will be insufficient. It estimates that replacing the Protecteur will cost about $3.28 billion, but that, given the stage of the program and uncertainty surrounding its characteristics, U.S. Government Accountability Office (GAO) best practice recommends budgeting no less than $4.13 billion.

> **Replace Protecteur**: PBO results are based on replacing the Protecteur, which is understood to satisfy DND's minimal requirements of logistics support at sea.
>
> **All acquisition costs**: The results include all acquisition costs, consistent with Treasury Board practice requiring inclusion of all overhead—DND employee salaries, pensions and benefits, and taxes.
>
> **Build in Canada**: The results are based on the National Shipbuilding Procurement Strategy (NSPS)'s "Build in Canada" condition and Canadian labor rates.

Background

In June 2010, the Government announced Canada's National Shipbuilding Procurement Strategy (NSPS) (Public Works and Government Services Canada, 2011). The NSPS aims to create a robust domestic shipbuilding industry to help the Government achieve its objectives for the Navy and Coast Guard outlined in the Canada First Defence Strategy (CFDS).

NSPS is a multi-departmental approach to federal procurement, which seeks to develop a longer-term, strategic relationship between government and industry by selecting two shipyards: one to build the combat work-package and the other to build the non-combat work-package of ships (National Defence and the Canadian Forces, 2008).

In October 2011, the selection was announced, with Seaspan's Vancouver Shipyards winning the non-combat package and Irving Shipbuilding in Halifax the combat package (Public Works and Government Services Canada, 2011).

In February 2012, the government and shipyards signed umbrella-agreements (Public Works and Government Services Canada, 2012). By and large, these agreements are not binding on the government or the shipyards. The only exception to this is a provision that outlines how the shipyards are to be compensated should the Government eliminate or reduce its planned procurements.[2]

In due course, separate, binding, individual contracts for each class of ship will be signed.

Once built, the JSS will replace the Navy's current AOR vessels—the Protecteur and the Preserver. These ships have been in operation for more than 40 years and are nearing the end of their service lives.

It is hoped the new JSS will provide core replenishment, underway medical-support to naval task groups, limited sealift capabilities, and limited support to forces ashore.[3]

JSS Program History. A letter was issued in February 2005 inviting companies to express interest in the project (MERX, 2005). Four industry teams were pre-qualified to compete (MERX, 2006). The Government issued a request for proposals (RFP) on July 1, 2006 (MERX, 2006).

The acquisition budget for the project was set at $2.1 billion accompanied by an $800 million service contract allotment.

In the project definition phase, two teams—ThyssenKrupp Marine Systems AG (TKMS) and SNC-Lavalin Profac Inc.—were each awarded a $12.5 million contract to produce and deliver an implementation proposal consisting of a preliminary ship design, a project implementation plan, and an in-service support plan. Those proposals were then evaluated to determine which demonstrated the best value.

In August 2008, the Government terminated the JSS project as both proposals were deemed to be non-compliant with the terms of the RFP. One team submitted a proposal for only two ships, while the other's proposal was significantly over budget (Defense Industry Daily, 2010).

In July 2010, DND issued background materials on a second attempt at the JSS project. In the new iteration, DND pegged the "total investment for the acquisition" at "approximately $2.6 billion," inclusive of taxes (National Defence and the Canadian Forces, 2010).

> **Understanding Government of Canada Budgets**
>
> Acquisition budgets must include all costs associated with a procurement, including: salaries, contributions to employee benefits and pensions, project management, contracts, design fees, licensing fees, industrial and regional benefits management, construction, quality assurance, contingency, and all applicable taxes (approx. 13%).

DND started by assessing then existing designs for vessels operating within a NATO Navy and meeting a minimum set of Canadian requirements.

In October 2010, an advanced contract award notice (ACAN)[4] was posted on the MERX procurement board announcing that the government had found only two suitable designs: ThyssenKrupp Marine Systems' Berlin Class and Navantia S.A.'s Cantabria Class (MERX, 2010).

TKMS was provided with $3.65 million to assess the risk of implementing the changes to make the Berlin meet the SOR. Once TKMS successfully completed this work, it was awarded an additional amount to undertake design development activities (DDA).

While the Cantabria also met the requirements, the Navy was unable to reach an agreement with Navantia.

Concurrently, the Navy contracted with BMT Fleet Technology (BMT)—a wholly owned subsidiary of BMT Group Ltd—to develop a "clean sheet" design. BMT was provided $9.8 million for this (BMT Fleet Technology, 2011, 2012).

DND will evaluate the two designs and select one prior to signing the design and build contract with Seaspan (MERX, 2012). Seaspan will then complete the production design and build the ships.[5]

At the time of publication, both TKMS and BMT were nearing completion of their DDA, and thus, no decision had yet been made as to the final design for the JSS.

Methodology

There are four main approaches to costing: analogy, parametric, build-up, and expert opinion. In cost estimating, the phase of the project and the availability of data drive methodology selection.

Given that the JSS is still in the early design phase (meaning that detailed specifications and actual costs are unavailable) and there are no recent, analogous acquisitions, parametric modeling is the most appropriate method for estimating cost.[6]

Parametric modeling involves positing cost relationships for a set of inputs and testing those relationships using historical data.

Developing and validating a parametric model requires a significant investment of time and access to a data set of historical costs. For this reason, the PBO used PRICE Systems' TruePlanning®—a software package used for estimating cost of hardware platforms.

> **TruePlanning®**
>
> TruePlanning® is a proprietary cost estimating tool that has applications in both military and non-military domains. It is backed by extensive military cost estimating expertise. Clients include the U.S. Department of Defense, Sikorsky Aircraft, NASA, BAE Systems, Gulfstream, United Technologies, and Boeing. For a full list, see: <http://www.pricesystems.com/success/customer_overview.asp>.
>
> It is among the only parametric software tools available to comprehensively cost military procurement. TruePlanning® is widely recognized and highly respected around the world as a robust military cost estimating tool.

Publicly available and confidential data were used as inputs for the model.[7] The reasonableness of all assumptions was tested by the PBO's Peer Review Panel and a team of subject matter experts (SMEs) at PRICE Systems.

Cost Drivers

The model has a number of cost drivers. These are discussed in detail in the "Methodology" section and in Appendix C: Model Inputs.

The major cost drivers of the model are weight and technology. In addition to weight and technology, other inputs drive the model, albeit less significantly.[8]

Weight. Weight refers to the ship's displacement. The larger the ship is, the more it is likely to cost to design and build. The PBO adopted the weight of the Protecteur for its point estimate.

Technology. Technology is a measure of how complicated constructing the platform is; for example, a ship is more complex than a car, but less complex than a fighter jet.

Technology is made-up of four key components:

1. Manufacturing complexity for structure;
2. Percent of new structure;
3. Percent design repeat for structure; and
4. Engineering complexity.

These variables are defined and discussed below.

Manufacturing complexity for structure. Manufacturing complexity for structure (MCPLXS) reflects the complexity of the technology involved,[9] its producibility (material machining and assembly tolerances, machining difficulty, surface finish, etc.) and yield.[10]

Analysis suggests that MCPLXS values range from 11.81 in the case of nuclear submarines to 4.02 in the case of destroyers and frigates; although, for some state of the art systems, they can be much higher.

The PBO had production cost and specification data for a number of logistics support ships.[11] These data were used as a basis for an MCPLXS assumption for the Protecteur.

First, the data were normalized. Tonnage for each vessel was converted to common units and costs to a common base year (BY).

Second, the costs and tonnage were fed into the model. The model then returned an MCPLXS for each ship.

The range of MCPLXSs for the ships was relatively tight compared to the ranges of MCPLXS for different platforms noted above. The U.S. Henry J. Kaiser class fleet oiler (a relatively simple oiler carrying victuals) had the lowest MCPLXS coming in at 3.39, and the U.K. Wave Knight class tanker had the highest coming in at 4.25. The Protecteur was in the mid to low range, with an MCPLXS of 3.78.

The PBO adopted the MCPLXS of the Protecteur for its point estimate.

Percent of new structure. Percent of new structure represents the amount of new structural design effort needed to complete the project. It may be less than 100% where old designs are adapted and reused in the new design.

> **Reusing Designs**
>
> Reusing designs sometimes makes sense, as it can reduce the amount of design work necessary. As such, although each ship type is a unique overall design in terms of size, shape and volume, ships may contain some designs from previous ships.
>
> Reusing designs, however, does not mean that a ship will require no new design effort. In fact, reusing existing design may also require design effort, as old designs are adapted to new requirements.[12]
>
> The team finally selected to design the JSS may reuse some design components from earlier projects. Even where this is so, however, it is likely that redesign will be required to adapt reused designs to Canadian operational requirements and make construction in a Canadian shipyard possible.[13]

The PBO adopted a value of 85% of new structure. This reflects the fact that any existing design will require significant redesign in order to ensure it responds to Canadian requirements and can be built in a Canadian shipyard. This figure was corroborated by examining Work Breakdown Structure (WBS) library and consulting with SMEs, members of PRICE's team and members of the Review Panel.[14]

Percent design repeat for structure. Percent of design repeat is determined by the ratio of redundant hardware to unique hardware.

> **Repeating Design**
>
> Assume that a gearbox has ten gears, five of which are identical. The component has a redundant hardware input of 4. Design repeat is 40% (four of ten gears are redundant).

The PBO adopted 40% design repeat for structure, reflecting the fact that there will be some, but not complete, symmetry in the design of the ship.

Engineering complexity. Engineering complexity reflects the experience and qualifications of the engineering design team.

It depends on two factors:

1. Scope of design effort
2. Experience of personnel

Scope of design effort describes the newness of the design task and the sophistication of the technology.

The JSS was determined to be a new design with existing technology because the ship is a unique build of currently existing technology.

> **Experience of personnel**
>
> Experience of personnel describes design team experience with the tasks being undertaken.
>
> RAND surveyed employee technical skills as part of a study on UK naval industry labor force. Based on its survey, it took technical workers between 6 and 8 years to reach 90% optimum productivity (see Figure 1) (Pung et al., 2008).

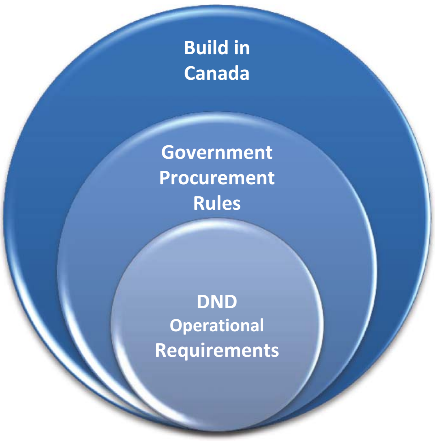


FIGURE 1 Total cost (*source*: PBO) (color figure available online).

FIGURE 2 RAND's productivity curve by technical skill, build, and support, The shaded region represents the productivity curve of various technical workers in the shipbuilding industry. RAND cites that, on average, it would take 6–8 years for technical workers to reach at least 90% of optimum productivity (*source*: Pung et al.).

> *"This is important to understand because simply employing a worker in a specific technical skill does not intrinsically equate to possessing the associated workforce capability—experience is critical in ensuring that the technical skill becomes a productive capability"* (Pung et al., 2008).

TKMS has designed and built a ship of this nature before. BMT has not. In this case, however, the finalist selected would only form part of the design team. In addition, it will be composed of Seaspan and a third party.

Thus, the personnel of at least two of the parties involved will have no project-specific experience. And, even if TKMS is selected, its personnel do not have project-specific experience designing and manufacturing in Canadian shipyards.

The PBO assumed a design team that has mixed experience. This reflects a value of 1.1.

Results

As mentioned above, the major cost drivers for the model are:

1. Weight;
2. Manufacturing complexity for structure;
3. Percent of new structure;
4. Percent of design repeat for structure; and
5. Engineering complexity.

As indicated, the inputs for the point estimate were:

1. Weight of 18,469,520 lbs (i.e., Protecteur's weight);
2. MCPLXS of 3.78 (i.e., Protecteur's MCPLXS);
3. Percent of new design of 85% (reflecting the significant redesign work that would be necessary to adapt any design to Canadian operating requirements and make it possible to be built in a Canadian shipyard);

4. Design repeat for structure of 40% (reflecting the fact that there will be some, but not complete, symmetry in the design of the ship);
5. Engineering complexity of 1.1 (i.e., a new design based on existing technology, designed and executed by a team with mixed experience and some product familiarity, thus reflecting Seaspan's current state.[15]

For these values, the model returned a point estimate of approximately $3.28 billion.

This analysis reflects planned project start and finish dates. If the project is put on hold or deviates from the schedule, this could affect the estimate. By way of illustration, RAND Corporation estimates that defense price escalation ranges between 7 and 11% per year (Arena et al., 2006).

As discussed, given that the project is early in its development and characteristics remain uncertain, the PBO varied the inputs in order to provide a sense of how much should be allocated to reduce the likelihood of program failure.

The inputs were varied as follows:

1. Weight was varied between 18,469,520 and 22,833,440 lbs (i.e., the Berlin-class).
2. MCPLXS was varied between 3.39 and 4.25 (i.e., the high and low of MCPLXSs for logistics support ships).[16]
3. Percent of new structure was varied between 50 and 85%.[17]
4. Percent of design repeat for structure was varied between 20 and 50%.[18]
5. Engineering complexity was varied between 0.9 and 1.1 (i.e., new design, existing technology designed and executed by a team with extensive experience and familiar with product compared to a team with mixed experience and some product familiarity).

Given the stage of the program and the uncertainty of the inputs, GAO best practice recommends budgeting at no less than a 50% confidence level (United States Government Accountability Office, 2009). For this confidence level, varying the inputs above, the PBO's model returns a value of $4.13 billion.

GAO on Ranges versus Point Estimates

"Having a range of costs around a point estimate is more useful to decision makers, because it conveys the level of confidence in achieving the most likely cost and also informs them on cost, schedule, and technical risks" (United States Government Accountability Office, 2009).

Analysis

Summary

The JSS project includes the acquisition of two Protecteur-class AOR ships.

The objective of the analysis is to determine if the $2.6 billion budget can cover all acquisition costs, inclusive of project management, contingencies, and taxes.

The PBO used a CER model to develop its ICE in the Canadian industrial base, based upon historical AOR ship programs and the JSS requirement.

The analysis was inclusive of JSS development and production costs; operations and support (O&S) costs were excluded.

> **Development and Production Costs**
>
> Development involves the process of designing and building the first ship in class. Creating a new ship type, even when existing designs are relied upon, is a resource-intensive process. It involves costs of initiation and planning, project management and control, quality assurance, development engineering, tooling, testing, and building the first ship.
>
> Production costs are those costs associated with building the ships that follow. While the first ship in class does not involve any production costs, successive ships in class will have diminishing development costs.

Analogous ship data, including ship class, lightweight displacement, contract year, and production unit cost were obtained through information requests and from publicly available sources. The PBO also collected industry documents to support the analysis.

The ICE was developed using inputs publicly available and confidentially obtained as parameters based on PBO and PRICE estimation team judgment and modeling best practices. The results are provided in Canadian dollars.

Point estimates are presented in Table 2, and risk-adjusted results, which modeled variability in numerous parameters (structural weight, MCPLXS, new design, design repeat and engineering complexity), are shown in Table 3.

The point estimates indicate a budget of $3.276 billion will be required to replace the *Protecteur* with two JSSs, within which the model only returns between a 15–20% of results. At the 50th percentile, a budget of $4.1 billion will be required. Table 3 carries the cost probability density function values.

Three sensitivity analyses were conducted to quantify the impact of a change in a specific cost driver in the ICE. The three analyses were as follows:

1. **Engineering Complexity**. The engineering complexity value, which measures the scope of the design effort and experience of shipyard personnel, was modified from the baseline value to calculate cost impact.
2. **Project Complexity**. The project complexity value, which indicates the complexity of the project in the context of planning and oversight activities, was modified from the baseline value to calculate cost impact.
3. **Quantity**: The procurement quantity was increased from two to three.

TABLE 2 Point estimates (billions)

Category	Cost
Program/Project	$0.98
Engineering	$1.35
Tooling and test	$0.13
Manufacturing	$0.50
Quality assurance	$0.33
Total	$3.28

Source: PBO.

TABLE 3 Confidence levels

Confidence (%)	Cost (billions)
5	$2.70
10	$2.96
15	$3.16
20	$3.32
25	$3.47
30	$3.60
35	$3.74
40	$3.87
45	$3.99
50	$4.13
55	$4.26
60	$4.40
65	$4.56
70	$4.72
75	$4.91
80	$5.13
85	$5.39
90	$5.74
95	$6.31

Source: PBO.

The sensitivity analysis identified that project and engineering complexity have a very strong influence on JSS acquisition cost (specifically, the experience of shipyard personnel is seen as the key cost driver). Producing a 3rd ship does not significantly add to program costs, as most of the costs are incurred during the development phase.

Methodology

The scope of the analysis is development and acquisition costs of two Protecteur-class AOR ships procured from the Canadian industrial base. Operating and logistic costs are not included.[19] This replacement is referred to as the JSS. The following section describes the techniques and methodologies used to develop the JSS estimate.

Cost Estimation Overview. The strategy used for the JSS estimate was to model Systems Engineering/Program Management (SE/PM) (System Catalog) and ship design, development and manufacturing activities (Hardware Catalog). The PBO reviewed and calibrated previous ship systems to decompose relationships between costs and ship size and technology.

Both cost objects listed above have a specific set of parameters, or cost drivers, which are described below.

- **System (SE/PM) Cost Object**: JSS requires a system cost object to account for SE/PM. SE/PM, as defined by MIL-HDBK-881, *"covers tasks associated with the overall planning, directing, and controlling of the definition, development, and production of a system [. . . but] excludes systems engineering and* *program management effort that can be associated specifically with the equipment (hardware/software) element."*

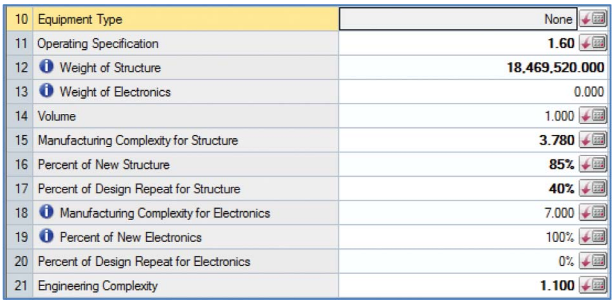
- **Hardware Component Object**: The JSS is modeled at the total ship level rather than at a lower WBS. Frequently, a large-scale estimate would include numerous hardware components (such as hull, propulsion, etc.). However, because ship data was available at the ship (and not sub-system) level, the PBO modeled the JSS estimate at the ship level. The PBO used the model's hardware component object, which includes physical inputs, such as weight (measured by ship displacement), and technical parameters such as MCPLXS, engineering complexity, and percent of new structure, which are listed in Figure 3 Hardware Component Input Sheet. Based on these inputs, as well as inherited quantity and schedule data from the system object, the model then calculated costs for development engineering, development manufacturing, development tool and test, production engineering, production manufacturing, and production tool and test.

To summarize, the PBO developed an acquisition estimate to include SE/PM, design and manufacturing costs calibrated with analogous ship programs to develop a data driven ROM estimate backed by the CER model, which holds industry average data and estimating relationships, driven by inputs.

Cost Estimation Process. The cost estimation process has been adapted from the GAO 12-step estimating approach (Figure 4).

The GAO steps, with specific aspects of the JSS ICE, are listed below:

1. *Define the estimate's purpose:* The purpose is to estimate JSS acquisition costs.
2. *Develop the estimating plan:* The cost team used TruePlanning® model.
3. *Define the program:* The program was defined as replacement of the Protecteur built in Canada according to Government of Canada procurement rules.
4. *Determine the estimating approach:* The estimating approach for each cost object was based upon data availability.
5. *Identify ground rules and assumptions (GR&A):* ICE GR&A were documented for all alternatives.
6. *Obtain the data:* Physical data from the Protecteur were collected (size, weight, etc.), which served as the JSS baseline. Analogous ship production cost data were collected and normalized, which supported MCPLXS calibration.[20]
7. *Develop the point estimate:* The cost estimate was developed in an iterative fashion, based upon known values (ship class, lightweight tonnage) and key parameters or



10	Equipment Type	None
11	Operating Specification	**1.60**
12	Weight of Structure	**18,469,520.000**
13	Weight of Electronics	0.000
14	Volume	1.000
15	Manufacturing Complexity for Structure	**3.780**
16	Percent of New Structure	**85%**
17	Percent of Design Repeat for Structure	**40%**
18	Manufacturing Complexity for Electronics	7.000
19	Percent of New Electronics	100%
20	Percent of Design Repeat for Electronics	0%
21	Engineering Complexity	**1.100**

FIGURE 3 Hardware component input sheet (*source*: TruePlanning®) (color figure available online).

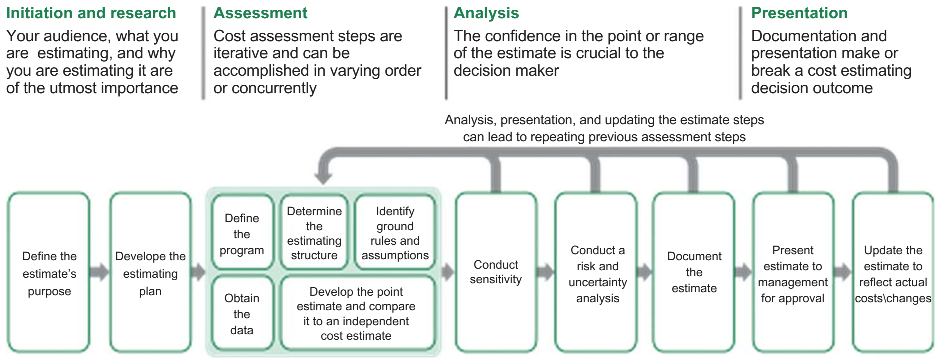


FIGURE 4 Cost estimation approach (*source*: U.S. GAO) (color figure available online).

cost drivers, such as MCPLXS, design repeat project complexity and engineering complexity. This ICE reflects "Canadian realities" (estimated in Canadian dollars, Canadian taxes, and shipyard capabilities).

8. *Conduct sensitivity:* Sensitivity analysis was developed around key cost drivers, measuring the cost impact of changes. Separate sensitivity analyses were undertaken, focused on engineering complexity, project complexity, MCPLXS, and acquisition quantity.
9. *Conduct risk and uncertainty analysis:* A risk assessment/analysis was conducted following the completion of the point estimates and is documented in Section 0. Risk analysis modeled a triangular distribution of likely ranges of possible weight, MCPLXS, percent new structure, design repeat, and engineering complexity.

Most work focused around GAO steps 5–9. Details of the steps involved in data collection, calibration, parametric modeling, sensitivity and risk analysis are listed below.

The cost team collected information from publicly available and confidential sources. The data was reviewed and validated by SMEs at PRICE Systems. Industry benchmarks were also researched, along with analogous programs and publicly available information, which were incorporated into the ICE. These parameters inputs were validated. Full listings of key input parameters, for each alternative's technology systems, are displayed in Appendix C: Model Inputs.

Data Collection and Data Sources. One of the key aspects of cost analysis is data collection. The PBO collected programmatic, technical and cost data at various stages of the analysis. A listing of data files obtained during the study period is listed Table 4.

Ground Rules and Assumptions. Ground rules and assumptions were followed. The estimate:

- includes development and production costs;
- is calculated in then-year Canadian dollars;
- assumes 2.0% annual escalation;
- assumes one prototype and one production system;
- assumes development begins March 1, 2014;
- assumes development first article (prototype) is delivered by April 30, 2018;
- assumes production first article (second ship) delivered by September 30, 2019;
- assumes 13% HST applied to contractor costs.

TABLE 4 Data collection summary

Documents/Interviews	Source
JSS Schedule	http://www.navy.forces.gc.ca/protecteur/1/1-s_eng.asp?category=17&title=578
JSS Statement of Operational Requirement, V5.5, 5/25/2009	DND
An Analysis of the Navy's Fiscal Year 2013 Shipbuilding Plan, 7/2012	US Congressional Budget Office
Internal Audit of JSS Project, Chief Review Services, 11/2011	http://www.crs-csex.forces.gc.ca/reports-rapports/pdf/2011/P0934-eng.pdf
JSS Schedule	http://www.materiel.forces.gc.ca/en/jss-sch.page?
Vancouver Shipyard Facility Brochure	http://seaspanfornsps.com/wp-content/uploads/2011/06/2011-Vanship-Brochure.pdf
Vancouver Drydock Facility Brochure	http://seaspanfornsps.com/wp-content/uploads/2011/06/2011-VDC-Brochure.pdf
Vancouver Drydock History Brochure	http://seaspanfornsps.com/wp-content/uploads/2011/06/Vessels-built-at-Vancouver-Shipyards-June-16-2011.pdf
JSS Project Status	http://www.materiel.forces.gc.ca/en/jss.page
Protecteur Acquisition Contract, Treasury Board, 12/16/66	Treasury Board

Source: PBO.

Data Normalization Process. PBO obtained database of ship data points, which included the following fields:

- Ship class
- Navy (country)
- Type of ship
- Number built
- Country of origin
- Shipyard
- Status
- Year(s) of construction
- Number built
- Contract year
- Size (tonnes light)
- Size (tonnes heavy)
- Complement (crew)
- Production cost per ship
- Cost type
- Cost notes

The database included fleet replenishment ships, fleet logistics tankers, JSSs, fast combat support ships (FCS), T-AKE dry cargo and ammunition ships, and oilers, with construction dates ranging from the 1980s to the present. Since the historical data was provided at the ship level, data cleansing, normalization, and calibration were done at the ship level. Thus, the JSS ICE is also modeled and estimated at the ship level. The key data elements required for the calibration are the weight and the unit production cost. The historical cost data provided weight, contract year, and cost of each ship. Production costs were normalized to 2012 U.S. dollars, based upon Naval Center for Cost Analysis indices, before calibration. Data points were removed where the shipbuilding was incomplete or costs included development as well as production. The intent of the normalization process was to eliminate the cost variability due to inflation and establish known production costs in a constant BY dollars. Table 5 displays the normalized ship data.

Protecteur data was obtained from a 1966 acquisition contract. The contract identified procurement of two ships for a cost of $51.7 million.

MCPLXS Calibration Process. Following data normalization, the next step involved calculating appropriate MCPLXS values, based upon the light displacement weight (weight of the ship excluding cargo, fuel, ballast, stores, passengers, and crew), operating specification, and normalized unit production cost. The calibration process determines the optimal MCPLXS value to produce a known unit production cost. The final step of the calibration process was to select an appropriate MCPLXS value for the JSS.

The operating specification value indicates the end user's requirements based on the planned operating environment for the hardware piece (ground, air, space, sea). It is a measure of the portability, reliability, structuring, testing and documentation requirements for acceptable contract performance. Operating specification has a significant impact on development engineering costs. The operating specification value was set to the "Military Ship" value of 1.6, as listed in Figure 5. Operating specification.

Weight was provided in the PBO ship database and was converted from metric tonnes to pounds for purposes of model input. Production unit costs, as described in Table 5, were converted into 2012 dollars prior to the calibration.

Calibrated MCPLXS values are listed in Table 6. The production unit cost (actual) column lists the production unit costs obtained from the database, while the amortized unit production cost lists the production costs calculated by the model from calibrated MCPLXS values.

TABLE 5 Normalized data

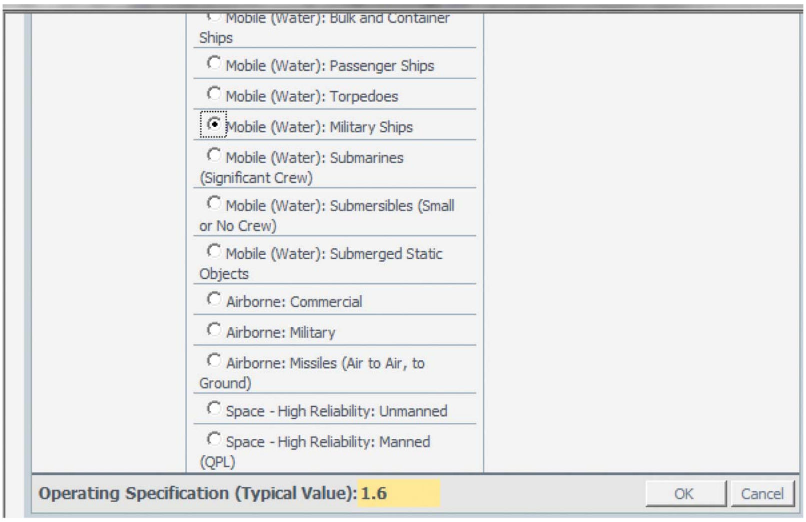
Ship or class	Type of ship	Base year	Tonnes light	2012 cost ($M)
Cantabria	Fleet replenishment ship	2005	9,800	$293
Berlin	Fleet logistic tanker	1997	10,360	$201
Berlin	Fleet logistic tanker	1998	10,360	$180
Karel Doorman (JSS)	Joint support ship	2009	20,703	$408
Amsterdam	Fast combat support ship	1995	17,040	$254
Lewis & Clark (1 in class)	T-AKE dry cargo and ammunition ship	2001	23,852	$498
Henry J. Kaiser	Oiler	1992	40,000	$149
Wave	Auxilary oiler	1997	31,500	$320
Protecteur	Oiler	1966	8,380	$116

Source: PBO.

TABLE 6 Calibration results

Cost Object Name	Cost Object Custom Name	Manufacturing complexity for structure	Weight of Stucture (lb)	Development Cost (Estimated)	Production Cost (Actual)
System Folder	JSS Calibration				
Hardware Component	Cantabria	4.13	21,599,200	$1,355,957,525	$293,580,924
Hardware Component	Berlin	3.71	44,608,960	$1,529,768,917	$201,268,043
Hardware Component	Berlin (2)	3.67	44,608,960	$1,463,061,180	$179,772,710
Hardware Component	Karel Doorman (JSS)	3.99	45,629,164	$2,043,902,043	$408,158,202
Hardware Component	Amsterdam	3.86	37,556,160	$2,570,897,691	$253,779,518
Hardware Component	Lewis & Clark	4.03	52,569,808	$2,333,265,242	$497,414,846
Hardware Component	Hernry J. Kaiser (2)	3.39	88,160,000	$1,781,233,214	$148,851,420
Hardware Component	Wace (2)	4.25	63,563,189	$3,276,716,539	$975,502,209
Hardware Component	Protecteur	3.78	18,771,200	$ 881,608,890	$115,890,891
Min	3.39				
Median	3.89				
Max	4.25				
Selected Value (rotecteur)	3.78				

Source: TruePlanning®.



○ Mobile (Water): Bulk and Container Ships
○ Mobile (Water): Passenger Ships
○ Mobile (Water): Torpedoes
● Mobile (Water): Military Ships
○ Mobile (Water): Submarines (Significant Crew)
○ Mobile (Water): Submersibles (Small or No Crew)
○ Mobile (Water): Submerged Static Objects
○ Airborne: Commercial
○ Airborne: Military
○ Airborne: Missiles (Air to Air, to Ground)
○ Space - High Reliability: Unmanned
○ Space - High Reliability: Manned (QPL)

Operating Specification (Typical Value): 1.6

FIGURE 5 Operating specification (*source*: TruePlanning®) (color figure available online).

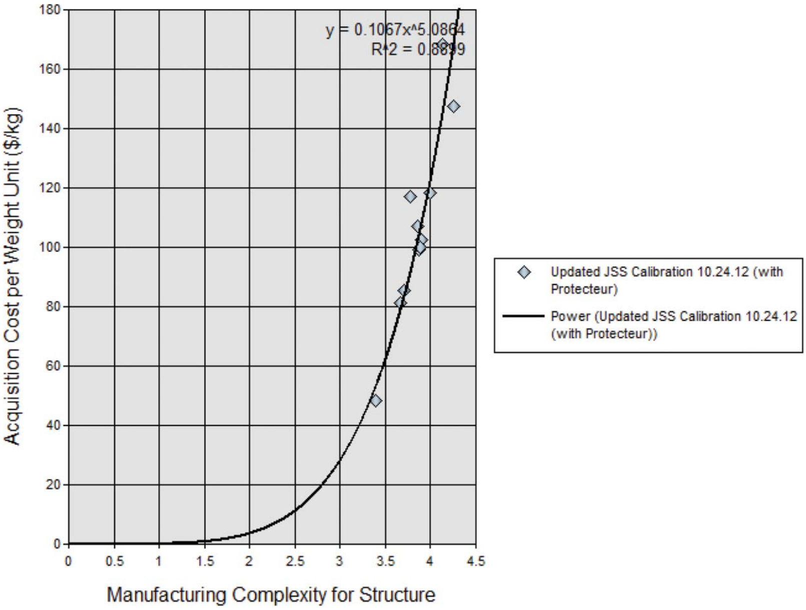
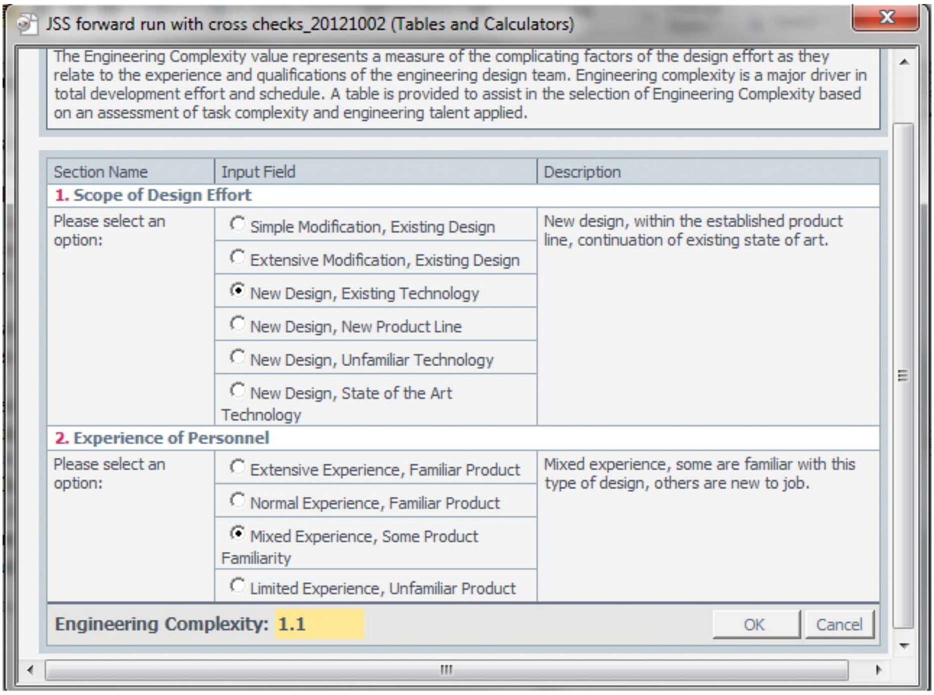


FIGURE 6 Manufacturing complexity vs. acquisition cost per unit weight (*source*: TruePlanning®) (color figure available online).

Figure 6 depicts the exponential relationship between MCPLXS and the unit cost per weight of all the known ship data points, with an R-squared value of 89%. The MCPLXS values varied from 3.39 to 4.25 with a median value of 3.9.

Discussions within the PBO and with SMEs resulted in the selection of the Protecteur ship's calibrated complexity value of 3.78 (Table 6) as the most conservative JSS complexity value. PBO identified that the JSS will at a minimum be similar to the Protecteur.



The Engineering Complexity value represents a measure of the complicating factors of the design effort as they relate to the experience and qualifications of the engineering design team. Engineering complexity is a major driver in total development effort and schedule. A table is provided to assist in the selection of Engineering Complexity based on an assessment of task complexity and engineering talent applied.

Section Name	Input Field	Description
1. Scope of Design Effort		
Please select an option:	○ Simple Modification, Existing Design	New design, within the established product line, continuation of existing state of art.
	○ Extensive Modification, Existing Design	
	● New Design, Existing Technology	
	○ New Design, New Product Line	
	○ New Design, Unfamiliar Technology	
	○ New Design, State of the Art Technology	
2. Experience of Personnel		
Please select an option:	○ Extensive Experience, Familiar Product	Mixed experience, some are familiar with this type of design, others are new to job.
	○ Normal Experience, Familiar Product	
	● Mixed Experience, Some Product Familiarity	
	○ Limited Experience, Unfamiliar Product	

Engineering Complexity: 1.1

FIGURE 7 JSS engineering complexity (*source*: TruePlanning®) (color figure available online).

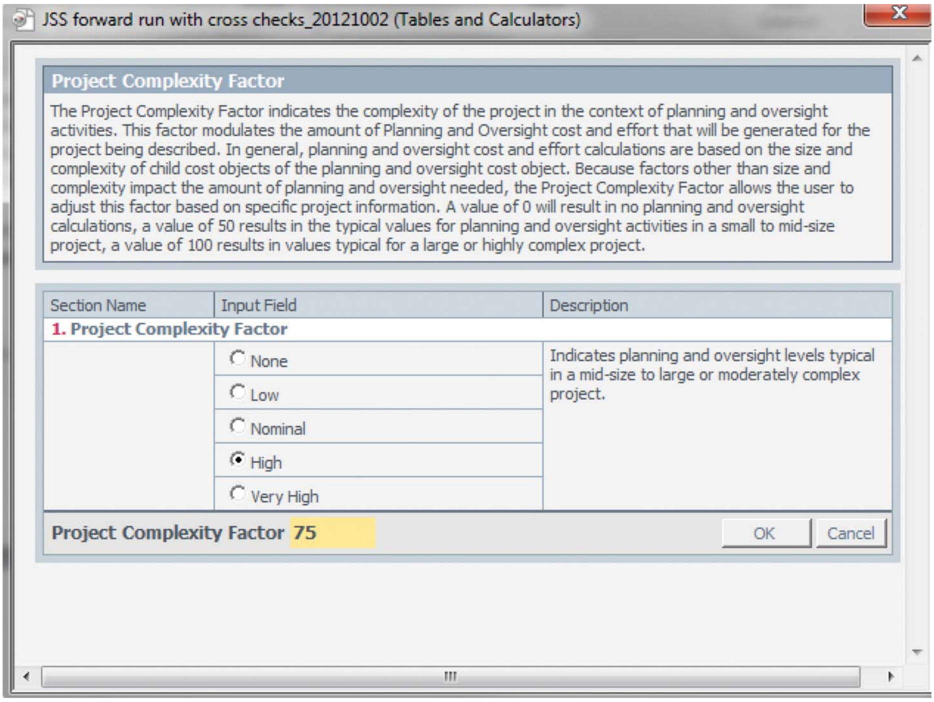
Costing a direct replacement of the Protecteur, therefore, would provide a defensible cost estimating approach, as there is high confidence in the Protecteur cost information, relative to the other data points. The Protecteur costs were based from data obtained in an acquisition contract. The selected JSS MCPLXS falls near the median of the boundary of analogous ship data points.

Parametric Model Development. To build the parametric model, the PBO chose to develop a “two box” estimate, to include a SE/PM and hardware component, and not a detailed subsystem level estimate. The database that was used to support MCPLXS calibration was at the system level (i.e., production costs were provided at the system level), which served to support the decision to estimate in a similar structure. Subsystem level analysis was not feasible given data constraints.

The acquisition quantity was set at two, acquisition schedule according to the RPP, and system weight—which assumes the Protecteur weight—at 8,380 tonnes light or 18,469,520 pounds (Royal Canadian Navy, 2003). One prototype and one production ship were estimated in Canadian dollars with an annual inflation rate of 2% reflecting CPI.

The key system object costs drivers are multiple site development, vendor interface complexity, and project complexity.

Multiple site development assumes two to three development locations with poor communication. High vendor interface and supervision requirements were assumed. Project complexity indicates the complexity of the project in the context of planning and oversight activities. The JSS Project is assumed to have high project complexity (Figure 8), representative of a large, complex project.[21]



JSS forward run with cross checks_20121002 (Tables and Calculators)

Project Complexity Factor

The Project Complexity Factor indicates the complexity of the project in the context of planning and oversight activities. This factor modulates the amount of Planning and Oversight cost and effort that will be generated for the project being described. In general, planning and oversight cost and effort calculations are based on the size and complexity of child cost objects of the planning and oversight cost object. Because factors other than size and complexity impact the amount of planning and oversight needed, the Project Complexity Factor allows the user to adjust this factor based on specific project information. A value of 0 will result in no planning and oversight calculations, a value of 50 results in the typical values for planning and oversight activities in a small to mid-size project, a value of 100 results in values typical for a large or highly complex project.

Section Name	Input Field	Description
1. Project Complexity Factor		
	○ None	Indicates planning and oversight levels typical in a mid-size to large or moderately complex project.
	○ Low	
	○ Nominal	
	● High	
	○ Very High	

Project Complexity Factor 75

FIGURE 8 JSS project complexity (*source*: TruePlanning®) (color figure available online).

The key hardware component object cost drivers are weight, operating specification, percent of new structure, percent design repeat for structure, and engineering complexity. Operating specification was set to Mobile-Military Ship. MCPLXS, as described in Table 6, was set to a value of 3.78. Engineering complexity measures the scope of the design effort and experience of shipyard personnel (Figure 8). PBO selected new design/existing technology and mixed team experience/some product familiarity, reflecting a value of 1.1 (Figure 7). A value of 1 would represent average or typical engineering complexity, thus the value of 1.1 represents a higher and more expensive degree of engineering complexity. New structure percentage of 85% and design repeat of 40% were selected.

Other parameters were left at default settings. A full listing and substantiation of the parameters is listed in Appendix C: Model Inputs.

Analysis

The analysis section contains the point and risk-adjusted estimates and sensitivity analysis.

Point Estimate. The JSS point estimate is \$3.276 billion, which includes \$3.044 billion in development and \$.232 billion in production costs, as listed in Table 7. Development costs represent non-recurring engineering and prototype development. Production includes the SE/PM and manufacturing costs of the second ship. To emphasize, the \$.232 billion applies only to the second ship.

TABLE 7 Activity name by phase results

	Costs: Updatesd JSS Calbration 10: Currency USD ($) (as spent)	Total	Dvelopemt	Production
1	Project Initiation and Planing for Development	**75.215.363**	75.215.363	
2	Project Management and Control for Development	**409.225.051**	409.225.051	
3	Quality Assurance for Development	**304.848.809**	304.848.809	
4	Configuration Management for Development	**278.622.672**	278.622.672	
5	Vendor Management for Development	**54.602.647**	54.602.647	
6	Document ation for Development	**107.455.046**	107.455.046	
7	Project Initiation and Planing for production	**4.137.313**		4.137.313
8	Project Management and control for production	**18.698.027**		18.698.027
9	Quality Assurance Management for production	**20.850.990**		20.850.990
10	Configuration Management for production	**17.160.943**		17.160.943
11	Vendor Management for production	**3.218.020**		3.218.020
12	Document ation for production	**7.938.203**		7.938.203
13	Development Engineering	**1.320.388.586**	1.320.388.586	
14	Development Manufacturing	**365.961.985**	365.961.985	
15	Development Tooling and Test	**128.161.644**	128.161.644	
16	Production Engineering	**29.360.129**		29.360.129
17	Production Manufacturing	**129.538.803**		129.538.803
18	Production Tooling and test	**1.100.276**		1.100.276
19	**Total**	**3.276.484.505**	**3.044.481.802**	**232.002.703**

Source: TruePlanning®.

Sensitivity Analysis. In this sensitivity analysis, the PBO analyzed the cost impact of the project complexity, engineering complexity, MCPLXS, and quantity.

Project complexity sensitivity. In this analysis, using the model's sensitivity analyzer, the PBO set the project complexity values range from low (value of 25) to very high (value of 100). The project complexity definitions are detailed below.

- Low (25): Planning and oversight levels typical in a small or simple project.
- Nominal (50): Planning and oversight levels typical in a small or mid-size project.
- High (75): Planning and oversight levels typical in a mid-size to large or moderately complex project.
- Very high (100): Planning and oversight levels typical in a large or highly complex project.

TABLE 8 Project complexity sensitivity analysis

Project complexity factor	Estimated cost (billion)
0	$1.97
5	$2.06
10	$2.15
15	$2.23
20	$2.32
25	$2.41
30	$2.50
35	$2.58
40	$2.67
45	$2.76
50	$2.84
55	$2.93
60	$3.02
65	$3.10
70	$3.19
75	$3.28
80	$3.36
85	$3.45
90	$3.54
95	$3.62
100	$3.71

Source: PBO.

Table 8 and Figure 9 display results of the project complexity sensitivity analysis (note that the baseline in a total cost of $3.276 billion assumes high project complexity). The delta between a nominal and high project complexity is estimated at $.434 billion.

Engineering complexity sensitivity. Engineering complexity value is a measure of the scope of the design effort and experience of shipyard personnel.

In this analysis, using the model's sensitivity analyzer, PBO set the engineering complexity values from 0.1 to 1.5. The engineering complexity parameter settings are listed in Table 9.

Table 10 and Figure 10 display the total cost impact due to engineering complexity. The impact of increasing the engineering complexity from 1.0 (new design, existing technology and normal experience, familiar product) to 1.1 (new design, existing technology and mixed experience, some product familiarity) is $.311 billion. It is noted that less experienced shipyard personnel, with no change in the scope of design effort, will have a significant cost impact on the program.

MCPLXS sensitivity. The MCPLXS value represents a technology index for the structural portion of the ship. MCPLXS is a measure of the ship's technology, its producibility (material machining and assembly tolerances, machining difficulty, surface finish, etc.), and yield. MCPLXS is a major cost and schedule driver.

The MCPLXS value (3.78) was determined from the Protecteur ship calibration. MCPLXS values from analogous program calibration ranged from 3.38 to 4.25.

In this analysis, using the model's sensitivity analyzer, the PBO set the MCPLXS values from 3.4 to 4.3. Table 11 and Figure 11 display the impact of total cost due to

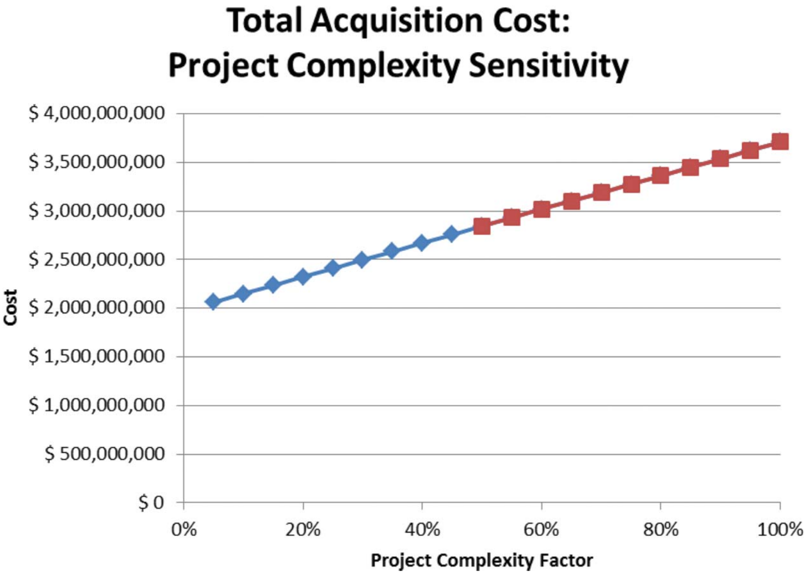


FIGURE 9 Project complexity sensitivity chart (*source*: PBO) (color figure available online).

TABLE 9 Engineering complexity values

	Experience of personnel			
Scope of design effort	Extensive, familiar product	Normal, familiar product	Mixed, some product familiarity	Limited, unfamiliar product
Simple modification, existing design	0.2	0.3	0.4	0.5
Extensive modification, existing design	0.6	0.7	0.8	0.9
New design, existing technology	0.9	1	1.1	1.2
New design, new product line	1	1.2	1.4	1.6
New design, unfamiliar technology	1.3	1.6	1.9	2.2
New design, state of art technology	1.9	2.3	2.7	3.1

Source: PBO.

MCPLXS. The total costs within the calibrated MCPLXS values ranged from $2.109 billion (MCPLXS: 3.4) to $5.285 billion (MCPLXS: 4.2). Figure 11 displays the non-linear relationship between MCPLXS and total acquisition cost.

Production quantity sensitivity. The final sensitivity reviewed the cost impact of delivering a third ship. The first ship is assumed to be a prototype. There is no increase in development costs, which is inclusive of the prototype system. Production costs are increased from $.232 billion to $.357 billion (a $.125 billion increase, or 54%) due to manufacturing an additional ship (Table 12). The costs for two ships are not twice that of a single ship due to economies of scale in the procurement phase and learning effects on both labor and materials (Figure 12).

TABLE 10 Total cost sensitivity on engineering complexity

Engineering complexity	Estimated cost (billions)
0.1	$0.8435
0.2	$0.9920
0.3	$1.1721
0.4	$1.3766
0.5	$1.6017
0.6	$1.8447
0.7	$2.1038
0.8	$2.3775
0.9	$2.6648
1	$2.9647
1.1	$3.2765
1.2	$3.5994
1.3	$3.9330
1.4	$4.2767
1.5	$4.6302

Source: PBO.

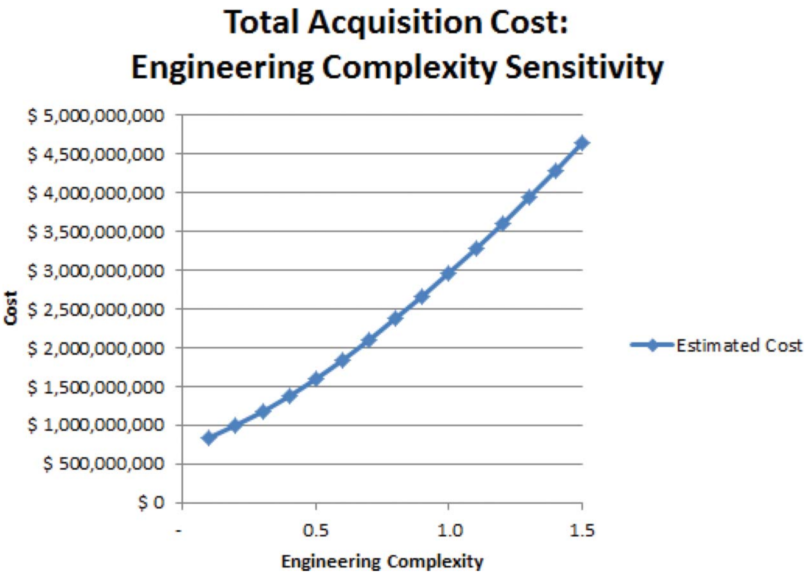


FIGURE 10 Total cost sensitivity on engineering complexity (*source*: PBO) (color figure available online).

Schedule Analysis. Schedule analysis modeled the cost penalty associated with constraining the schedule to deliver two ships by September 2019, compared against an “unconstrained schedule” estimate.

The baseline schedule assumes the program begins in March 1, 2014, development first article milestone (prototype) on April 30, 2018, and production first article on September 30, 2019. The unconstrained schedule assumes a development start date of March 2014, and the model forecasts an optimal schedule.

TABLE 11 Total cost sensitivity on MCPLXS

MCPLXS	Estimated cost (billions)
3.4	$2.11
3.5	$2.37
3.6	$2.66
3.7	$2.99
3.8	$3.35
3.9	$3.76
4.0	$4.22
4.1	$4.72
4.2	$5.28
4.3	$5.91

Source: PBO.

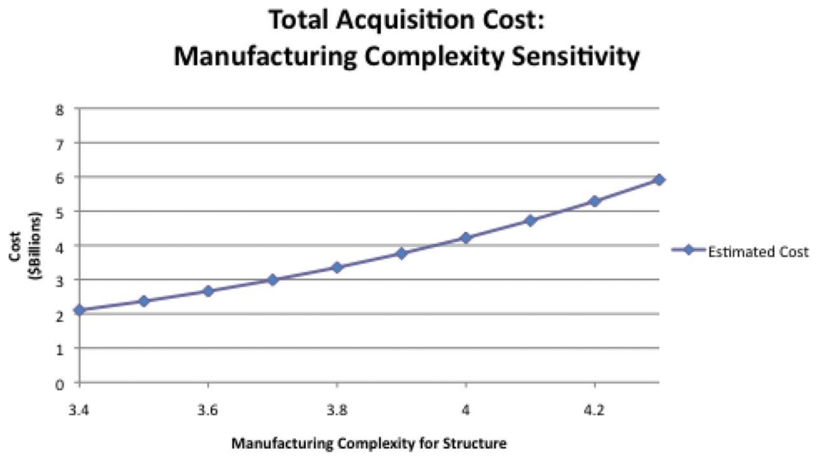


FIGURE 11 Total cost sensitivity on MCPLXS (*source*: PBO) (color figure available online).

The optimal schedule forecasts production first article in April 2023, which is a 3½ year extension from the baseline schedule. Schedule parameters for the baseline and unconstrained schedule are displayed in Figures 13 through 16.

These results indicate that cost savings associated with extending the schedule outweigh the effects of defense price escalation (Figure 17). This does not mean, however, that the schedule ought to be extended, as operational requirements and vendor resources may not permit extension.

The "schedule penalty," which measures additional costs required to complete the project within six years, is $.852 billion, as displayed in Table 13 Schedule analysis summary. This includes costs to complete the development effort in a compressed time period, ramp up the production line, and stay within the critical schedule path. Significant resources have to be added earlier in the development and production period to complete and meet the compressed schedule, resulting in higher costs and greater risk.

Cross-Checks. As a cross-check, PBO developed acquisition cost estimates for the Cantabria, Berlin, Karel Doorman, Amsterdam, and Lewis & Clark (Figure 18). The

TABLE 12 Production quantity sensitivity results

3 1 Prototype, 1 production system (billions)	
Program/Project	$0.976
Engineering	$1.350
Tooling and test	$0.129
Manufacturing	$0.496
Quality assurance	$0.326
Total	$3.276
1 Prototype, 2 production systems (billions)	
Program/Project	$1.002
Engineering	$1.350
Tooling and test	$0.130
Manufacturing	$0.583
Quality assurance	$0.336
Total	$3.401

Source: PBO.

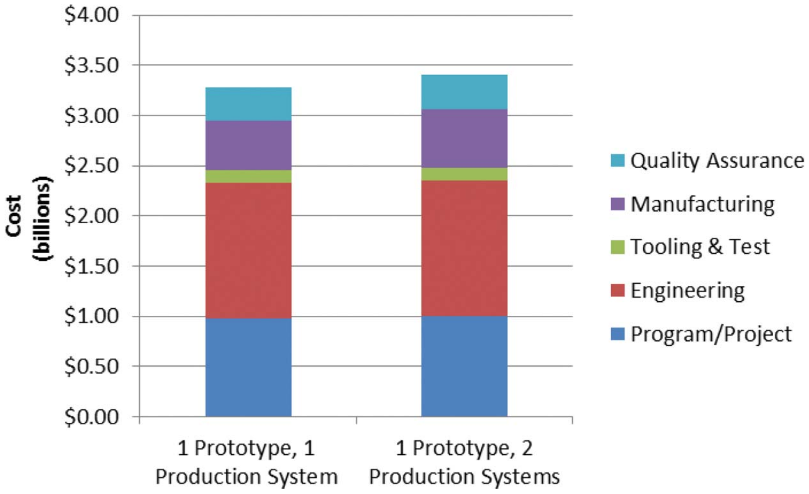
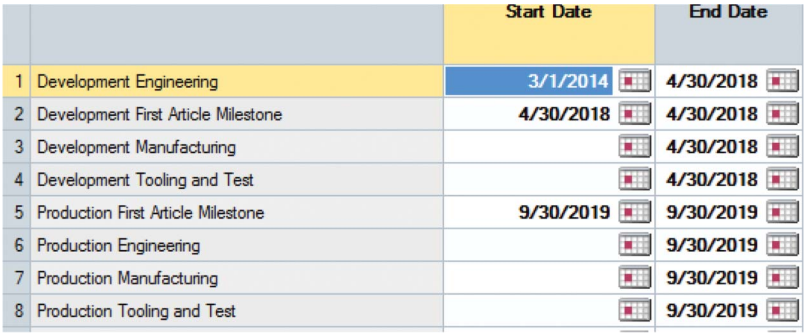


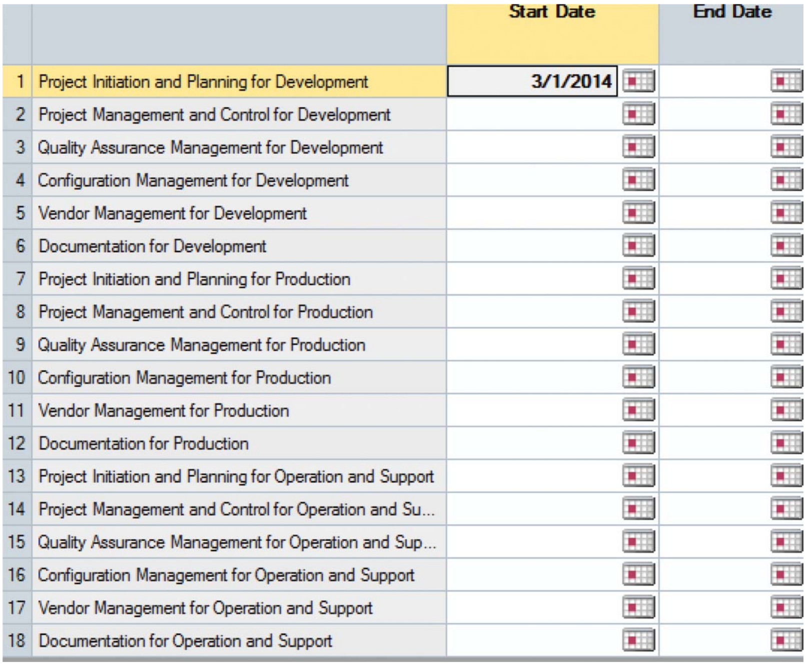
FIGURE 12 Production quantity chart (*source*: PBO) (color figure available online).

development and production cost of each ship was estimated using the model with the same technical and programmatic input parameters as JSS except MCPLXS (such as quantity, schedule, project complexity, vendor interface complexity, engineering complexity, percent of new structure, or percent of design repeat). Each ship estimate was based on the assumption that ships would be built today, in the same shipbuilding environment as the JSS. Each ship's weight was based on the actual ship weight, and its MCPLXS was based on its calibrated MCPLXS value. The JSS project is assumed to be built and executed in a ship building environment that is not experienced in building similar ships with a limited experienced engineering team. The results are shown in Table 14. The JSS cost per weight (kg) is within 17% of the Berlin, Amsterdam, and Lewis & Clark ship estimates.



		Start Date	End Date
1	Development Engineering	3/1/2014	4/30/2018
2	Development First Article Milestone	4/30/2018	4/30/2018
3	Development Manufacturing		4/30/2018
4	Development Tooling and Test		4/30/2018
5	Production First Article Milestone	9/30/2019	9/30/2019
6	Production Engineering		9/30/2019
7	Production Manufacturing		9/30/2019
8	Production Tooling and Test		9/30/2019

FIGURE 13 System object schedule (baseline) (*source*: TruePlanning®) (color figure available online).



		Start Date	End Date
1	Project Initiation and Planning for Development	3/1/2014	
2	Project Management and Control for Development		
3	Quality Assurance Management for Development		
4	Configuration Management for Development		
5	Vendor Management for Development		
6	Documentation for Development		
7	Project Initiation and Planning for Production		
8	Project Management and Control for Production		
9	Quality Assurance Management for Production		
10	Configuration Management for Production		
11	Vendor Management for Production		
12	Documentation for Production		
13	Project Initiation and Planning for Operation and Support		
14	Project Management and Control for Operation and Su...		
15	Quality Assurance Management for Operation and Sup...		
16	Configuration Management for Operation and Support		
17	Vendor Management for Operation and Support		
18	Documentation for Operation and Support		

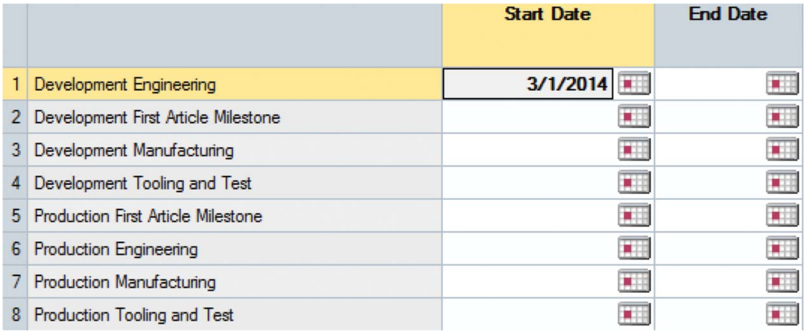
FIGURE 14 Hardware component schedule (baseline) (*source*: TruePlanning®) (color figure available online).

Risk Analysis. Due to the inherent uncertainty involved in developing comprehensive cost estimates, the cost team utilized the model's in-built risk analysis in an attempt to quantify the risk associated with individual parameters and assumptions.

Risk analysis modeled a triangular distribution of likely ranges of possible weight, MCPLXS, percent new structure, design repeat, and engineering complexity (Table 15).

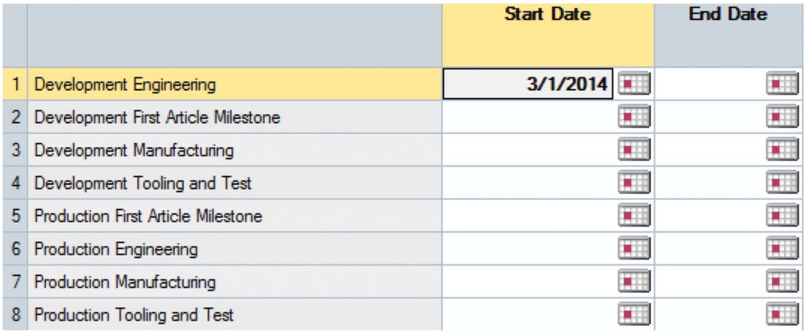
The MCPLXS range was determined from the ranges in the calibrated complexity values.

The weight assumes that the JSS weight will not be less than that of the Protecteur, but could increase by approximately 25%.



		Start Date	End Date
1	Development Engineering	3/1/2014	
2	Development First Article Milestone		
3	Development Manufacturing		
4	Development Tooling and Test		
5	Production First Article Milestone		
6	Production Engineering		
7	Production Manufacturing		
8	Production Tooling and Test		

FIGURE 15 System object schedule (unconstrained) (*source*: TruePlanning®) (color figure available online).



		Start Date	End Date
1	Development Engineering	3/1/2014	
2	Development First Article Milestone		
3	Development Manufacturing		
4	Development Tooling and Test		
5	Production First Article Milestone		
6	Production Engineering		
7	Production Manufacturing		
8	Production Tooling and Test		

FIGURE 16 Hardware object schedule (unconstrained) (*source*: TruePlanning®) (color figure available online).

TABLE 13 Schedule analysis summary (billions)

Fiscal year	Baseline	Unconstrained schedule	Schedule penalty
2014	\$0.4933	\$0.1519	(0.3414)
2015	\$0.9548	\$0.3201	(0.6348)
2016	\$0.8973	\$0.3390	(0.5583)
2017	\$0.6406	\$0.2973	(0.3434)
2018	\$0.2410	\$0.4226	\$0.1816
2019	\$0.0493	\$0.4193	\$0.3700
2020		\$0.2329	\$0.2329
2021		\$0.1118	\$0.1118
2022		\$0.1139	\$0.1139
2023		\$0.0152	\$0.0152
Total	\$3.2765	\$2.4240	(0.8525)

Source: PBO.

The percent new structure value of 85% represents a conservative (minimal design reuse) position, thus the point and pessimistic values are identical, and the optimistic value of 50% was based on SME input.

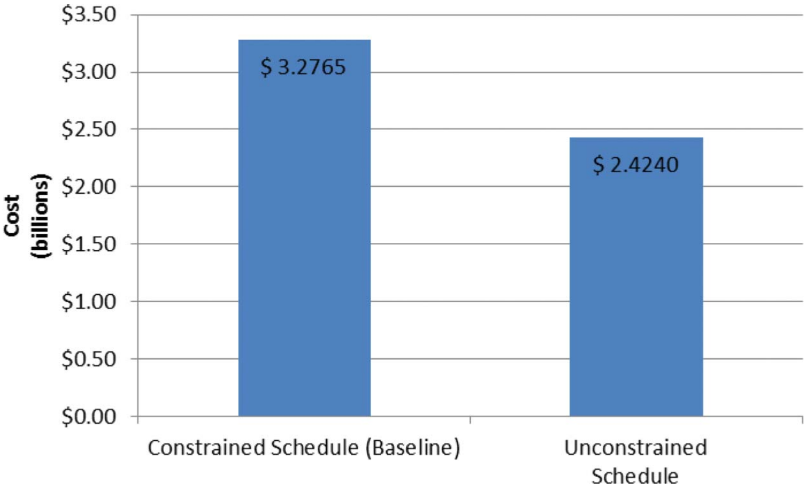


FIGURE 17 JSS schedule analysis (*source*: PBO) (color figure available online).

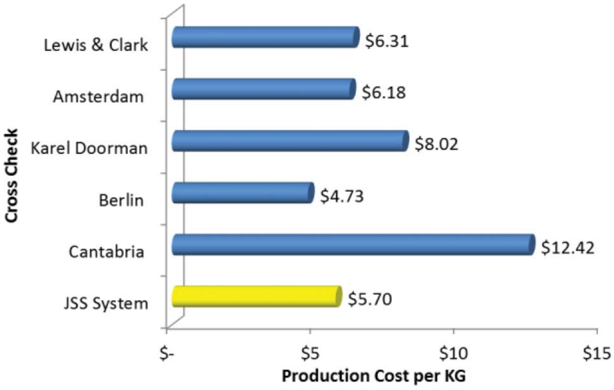


FIGURE 18 Cost per kg cross-check. *Note*: These figures assume no redesign work necessary to adapt the ship to Canadian operating requirements and building in Canada (*source*: PBO) (color figure available online).

TABLE 14 Total cost cross-check (CDN TY$)

	Total cost (billions)	Weight (lbs)	MCPLXS
JSS	4.1	18,469,520	3.9
Cantabria	5.8	21,599,200	4.1
Berlin	4	22,833,440	3.7
Karel Doorman	9.1	45,629,164	4.0
Amsterdam	6.9	37,556,160	3.9
Lewis & Clark	9.3	52,569,808	4.0

Source: PBO.

TABLE 15 Risk parameters

	Baseline	Pessimistic	Optimistic
Weight of structure (lbs)	18,469,520	22,833,440	18,469,520
MCPLXS	3.78	4.25	3.39
% new structure	85%	85%	50%
% design repeat for structure	40%	20%	50%
Engineering complexity	1.1	1.1	0.9

Source: PBO.

Percent design repeat assumes an optimistic input of a symmetrical design (50% repeat), while the pessimistic input assumes much less design repeat.

Engineering complexity in the baseline and pessimistic scenario assume new design/existing technology and mixed experience/some product familiarity, while the optimistic scenario is based upon new design/existing technology and extensive experience/familiar product.

It is important to note that the wider the uncertainty around the input parameters, the greater the probability of the estimate exceeding the "point" or "most likely" estimate. This uncertainty is expressed in terms of a "confidence" level.

A point estimate at the 80% confidence level means the estimate has a 20% chance of exceeding the point estimate at 80% chance of coming in at or below the point estimate.

Observations

Risk analysis identified a cost risk range of $2.7–6.3 billion (Figure 19, Table 16). The analysis indicates that it is not feasible to produce two AOR ships within the current budget holding all specifications and other inputs constant. The budget envelope of $2.6 billion is unlikely to be feasible given Canadian shipyard realities, schedule constraints, and likely "unknown-unknowns" that have yet to be identified. Additionally, the FOC date of September 2019 is optimistic, and holding to this schedule could result in up to $.8 billion in additional costs.

FIGURE 19 JSS cumulative distribution (*source*: TruePlanning®) (color figure available online).

TABLE 16 JSS risk-adjusted results (*source*: PBO)

Confidence	Total acquisition costs (in billions)
5%	$2.70
10%	$2.96
15%	$3.16
20%	$3.32
25%	$3.47
30%	$3.60
35%	$3.74
40%	$3.87
45%	$3.99
50%	$4.13
55%	$4.26
60%	$4.40
65%	$4.56
70%	$4.72
75%	$4.91
80%	$5.13
85%	$5.39
90%	$5.74
95%	$6.31
Standard Deviation	$1.12
Mode	$3.86
Mean	$4.27

At the 50th percentile confidence, JSS acquisition costs are predicted to be $4.13 billion, which represents a 26% increase above the point estimate. The reason for the significant increase is because the cone of uncertainty is quite wide at a pre-design stage. As the program advances and inputs become certain, the spread of values provided for different confidence levels will narrow (see Figure A2).

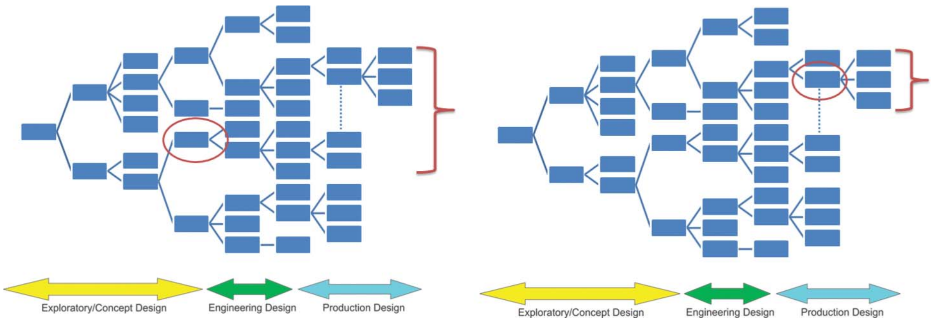


FIGURE A2 Estimate refinements as decisions are made (*source*: PBO) (color figure available online).

List of Acronyms

ACAN	Advanced Contract Award Notice
AOR	Auxiliary Oiler Replenishment Ship
BY	Base Year
CER	Cost Estimating Relationship
CFDS	Canada s Defence Strategy
CY$	Constant-Year Dollars
DDA	Design Development Activities
GAO	U.S. Government Accountability Office
ICE	Independent Cost Estimate
JSS	Joint Support Ship
MCPLXS	Manufacturing Complexity for Structure
NSPS	National Ship Procurement Strategy
O&S	Operations and Support
PBO	Parliamentary Budget Officer
RFP	Request for Proposals
ROM	Rough Order of Magnitude
SE/PM	Systems Engineering/Program Management
SME	Subject Matter Expert
SOR	Statement of Requirements
TY$	Then-Year Dollars
WBS	Work Breakdown Structure

Acknowledgments

The authors would like to thank the members of the independent Peer Review Panel for their comments and guidance. The authors also wish to thank Eric Wertheim, Andy Nicholls, and numerous naval experts for sharing their expertise; Peter Weltman, Sahir Khan, Mostafa Askari, and Jason Lee for helpful comments; and Pat Brown, Jocelyne Scrim, and Adam Pennell for their assistance in preparation. Any errors or omissions are the responsibility of the authors. Please contact Erin Barkel (E-mail: erin.barkel@parl.gc.ca) for further information.

Notes

1. DND briefing provided two estimates: $2.533 billion for new design and $2.518 for Military Off the Shelf. PBO presents the average of these. Of note is that these estimates fall below DND's 2008 estimate of $2.96 billion for two Canadian AORs. DND, "Preliminary Cost Analysis for PROTECTEUR Class Replacement," dated 29 August 2008. Using DND's escalation rates, this would bring this estimate in line with the PBO's at $3.2 billion.
2. Government of Canada, *Umbrella Agreement Between Vancouver Shipyards Co Ltd and Seaspan Marine Corporation and Her Majesty the Queen in right of Canada, as represented by the Minister of Public Works and Government Services* (Ottawa: National Shipbuilding Procurement Strategy, 2012) at s 6.9.
3. The project has four main deliverables: (1) design of a new class of ship; (2) construction of two ships, with an option for a third; (3) provision of the necessary infrastructure and other logistics support to facilitate the transition of the new ships into service; and (4) in-service support contract to provide maintenance, repair and overhaul, long-term spares, and technical support

for the life of the ships. National Defence and the Canadian Forces, *Joint Support Ship (JSS)* (8 August 2011), online: National Defence and the Canadian Forces <http://www.forces.gc.ca/aete/jointsupportshipjss-projetdunaviredesoutieninterarmeesnsi-eng.asp>; National Defence and the Canadian Forces (12 May 2008), *supra* note 7.

4. An advanced contract award notice is a contracting vehicle used by the Government of Canada to expedite the procurement process typically used when it is believed that only one supplier is capable of meeting the procurement requirements. Notice is posted for no less than 15 calendar days to allow other parties to indicate if they would be able to meet the requirement. In this case, presumably, an ACAN was used to confirm that only two NATO ship designs met the requirements for the JSS. Refer to: Treasury Board of Canada Secretariat, *Guide for Managers—Best Practices for Using Advanced Contract Award Notices (ACANS)* (January 2004), online: Treasury Board of Canada Secretariat <http://www.tbs-sct.gc.ca/pubs_pol/dcgpubs/contracting/acan_guide01-eng.asp>.
5. Public Works and Government Services Canada, *Joint Support Ship (JSS) Project* (25 May 2011), online: <http://www.tpsgc-pwgsc.gc.ca/app-acq/stamgp-lamsmp/nsi-jss-eng.html>.
6. *Ibid*.
7. Including the SOR, documentation for the Protecteur, and data relating to similar AOR ships that include a range of potential mission solutions. See Appendix B: JSS High Level Requirements. Confidential data was obtained by information requests.
8. See Appendix C: Model Inputs.
9. Technology represents the impact to all of the component's manufacturing operations including material, labor, process, equipment, etc.
10. During any manufacturing operation, there will be some components or sub-assemblies that may have to be reworked or scrapped, requiring additional material and labor resources. This is more predominant in prototype than in the production ship. For example, if the yield is 50% in prototype, it means the builder would need to spend twice more on material and labor.
11. See list of ships in Appendix E: List of Replenishment Vessels.
12. Note that it is possible that using old designs may actually result in more design effort being required as a result of trying to adapt an existing design ill-suited to new requirements. Note as well that subject matter experts familiar with TruePlanning® confirmed that they have never come across a new ship that requires no new design effort.
13. For example, TKMS would have to change the existing design of the Berlin Class's electrical system to accommodate North American standards for voltage and amperage, add two goalposts (refueling masts), and adapt its design to modular construction significantly smaller than those used in Germany. This will require significant new design effort.
14. The WBS revealed that approximately 22% of its elements could be taken from existing design libraries. This results in 78% of design being created from scratch. That does not mean, however, that the 22% would require no redesign effort. Adapting these designs to ensure they comply with Canadian operating requirement and can be executed in a Canadian shipyard will require additional design effort.
15. For more information, please consult *Capacity Analysis of the Vancouver Shipyards.* This analysis was published as an annex to PBO's original report and is available online at: <http://www.pbo-dpb.gc.ca/files/get/publications/252?path=%2Ffiles%2Ffiles%2FJSS_EN.pdf>
16. See 2.2.6 MCPLXS Calibration Process.
17. While 85% new structure is reasonable and reflective of the work that needs to be undertaken, it is possible that that figure may be lower. In order to enhance the defensibility of its range, PBO adopted a conservative figure for the low end of percent of new structure. This increases the likelihood of the simulation returning results with a lower cost.
18. Here, 20% represents a pessimistic outcome, but one that nonetheless seems within the range of possibilities given the different systems the ship may ultimately contain.
19. The main platform for considerations is the 2009 SOR, while the two excursions are to reflect the original (2006) SOR and the minimal AOR requirements. The necessary model calibrations were made to reflect the Canadian shipbuilding environment.

20. Unit production cost data is assumed to exclude program-level SE/PM. Thus, the calibration file included a Hardware component only, and excluded a System Cost Object. However, the Hardware Cost object does include equipment-specific SE/PM.
21. In this case, there will be three active locations (i.e., the client (DND), the designer (TKMS or BMT), and Seaspan). Federal procurement rules put certain restrictions on the ability of contractors to communicate with federal employees. Since the Government must facilitate communication between the shipyard and the designer, delays or restrictions are likely. Where the communication between three active locations is characterized as poor, TruePlanning® ascribes a value of 2.5.
22. The Department of National Defence has approved Version 5.6 but no longer shares the document with outside parties. Government officials have indicated that small adjustments were made to the requirements, most notably to indicate that the essential requirements were subject to design to budget constraints.
23. Knot (kt) is one nautical mile per hour.
24. See Appendix D: Current Project Schedule.
25. *Ibid.*
26. Laid down: The term *laid down* was originally used to mark the beginning of construction on a ship's keel. Since many modern ships are now constructed in modules, the term *laid down* is now more generally used to mark the beginning of the construction of a ship.
27. Launched: Once the hull of a ship is completed, it may be *launched* from the shipyard into the water.
28. Commissioned: A ship is *commissioned* when it is deemed ready for service.

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Mr. Yalkin began his university career at the University of British Columbia where he completed an Honours Bachelor of Commerce in Business and Managerial Economics. Following graduation, he moved to Australia where he received his LLB from the University of Sydney, and was admitted to the Supreme Court of New South Wales. While in Australia he was employed by the office of the Legal Services Commissioner and by Clayton Utz, where he worked primarily in banking and financial regulation. After leaving Australia, Mr. Yalkin pursued graduate studies at Oxford University. He received both a BCL and an MPhil in Law, graduating with distinction from both programs.

Appendix A: Interpreting Parametric Cost Estimates on a Budget Envelope

When generating a parametric cost estimate, the cost estimator may choose to present the result as either a point estimate or a range. Depending on the circumstances, one or both of these descriptions of the results may be appropriate. The purpose of this appendix is to provide the reader with a better understanding of how, in this case, the decision was made to present the JSS estimate as range as opposed to a point estimate.

> **Excerpts from the GAO's Cost Estimating and Assessment Guide Point Estimates Alone Are Insufficient for Good Decisions (p. 154)**
>
> *"Since cost estimates are uncertain, making good predictions about how much funding a program needs to be successful is difficult. In a program's early phases, knowledge about how well technology will perform, whether the estimates are unbiased, and how external events may affect the program is imperfect. For management to make good decisions, the program estimate must reflect the degree of uncertainty, so that a level of confidence can be given about the estimate.*
>
> *Quantitative risk and uncertainty analysis provide a way to assess the variability in the point estimate. Using this type of analysis, a cost estimator can model such effects as schedules slipping, missions changing, and proposed solutions not meeting user needs, allowing for a known range of potential costs. Having*

> *a range of costs around a point estimate is more useful to decision makers, because it conveys the level of confidence in achieving the most likely cost and also informs them on cost, schedule, and technical risks.*
>
> *Point estimates are more uncertain at the beginning of a program, because less is known about its detailed requirements and opportunity for change is greater. In addition, early in a program's life cycle, only general statements can be made. As a program matures, general statements translate into clearer and more refined requirements that reduce the unknowns. However, more refined requirements often translate into additional costs, causing the distribution of potential costs to move further to the right."*

Budgeting to a Realistic Point Estimate (p. 158)

> *"Management can use the data in an S curve to choose a defensible level of contingency reserves. While no specific confidence level is considered a best practice, experts agree that program cost estimates should be budgeted to at least the 50 percent confidence level, but budgeting to a higher level (for example, 70 percent to 80 percent, or the mean) is now common practice. Moreover, they stress that contingency reserves are necessary to cover increased costs resulting from unexpected design complexity, incomplete requirements, technology uncertainty, and industrial base concerns, to name a few uncertainties that can affect programs."*

The JSS procurement may be viewed as a series of decisions, the first among them the decision of DND to replace the Protecteur-class AOR. By the time that this new acquisition was announced, a number of other decisions had been made, including: the total budget of the project, when the navy would take delivery of the ship, and the high-level features of the ship. Since the announcement, further decisions have been made with respect to the requirements of the ship, the shipyard at which the ship will be constructed, and which design firms will be competing for the final design contract. Each decision made to date has had either a positive or a negative impact on the budget. For example, a decision to shed a capability can reduce the budget, while a decision to compress the schedule can increase the budget.

There are still many decisions that remain to be made at this stage of the JSS project. In constructing the cost estimation model, the PBO accounted for these uncertainties through a sensitivity analysis, and the resulting estimate varies significantly depending on the desired confidence level. The amount of uncertainty made it prudent to present the results as a range—rather than a point estimate. This enables parliamentarians to better understand the potential implications of the decisions made and to be made.

As more decisions are made and it becomes possible to further refine the model, this range of possible outcomes will shrink (see Figure A2). Once the requirements for the project are further solidified, possibly when the design is announced, there will be more detailed information with which to populate the model and reduce the sensitivity around certain variables. At such a time, if parliamentarians request it, the PBO can update the JSS cost estimate model. Depending on the level of data available, the PBO may be able to present a point estimate at an appropriate confidence level.

Appendix B: JSS High Level Requirements

The table is adapted from the JSS Statement of Requirement Version 5.5 (November 2009).[22]

Capability		Essential requirement	Desirable requirement
Cargo fuel	F76 (military diesel)	7,000 tonnes	
	F44 (military aviation kerosene)	980 tonnes	
Replenishment at sea (RAS)	Number of stations	4 (two stations per side)	+ Astern refuelling station
Aviation	Number of helicopters	3	4
	Flight deck spots	1	2
Maximum sustained speed		20 kt[23]	22 kt
Survivability	NIXIE (torpedo decoy)	DG	Acoustic/IR/RCS signature management
		CBRN (chemical, biological, radiological, and nuclear)	Enhanced damage stability
Maneuverability		Bow thruster	
Ice capability		Ability to access Nanisivik Facility in summer navigation season	ASPPR type C can enter zone 6, while type E cannot
		Arctic shipping pollution Prevention regulations (ASPPR) type E	
Operations functions	C4I (command, control, communications, computers, and intelligence)	Basic (current AOR 509)	Integrated/Networked
	Self defense	2 close-in weapon systems (CIWS)	CIWS

(*Continued*)

Appendix (Continued)

Capability		Essential requirement	Desirable requirement
		stand-alone electronic countermeasures (ECM) Defense against small boat threats (DASBT) mounts	ECM Electronic surveillance measures (ESM) DASBT integrated in Command and control system (CCS)
Accommodations		250 people	320 people
Medical		Role 2E (tactical medical evacuation)	
Cargo transfer systems	Containers	TEUs (twenty-foot equivalent unit)	Self-unloading alongside and at anchor
	Alongside jetty	Cranes	
	At anchor	Cranes and landing craft, vehicle, personnel (LCVP)	Landing craft utility (LCU)
Afloat JTFHQ		Space and weight only	Fitted for but not with (FFBNW) associated C4

Appendix C: Model Inputs

Level	Variable	Input	Explanation
System	Number of units	2	TruePlanning® differentiates between costs associated with producing the prototype, or first ship in class, and costs associated with producing actual production units—those ships in class that follow the prototype unit. This distinction is made because the cost associated with producing the first ship in class is significantly higher than that of the production units that follow. Consistent with the Government's stated policy of building two JSSs with an option for a third, the inputs of the model have been set at one prototype and one or two production units.
SE/PM	Operating specification	1.60 Mobile (Water): Military Ships	The operating specification refers to the equipment's planned use (e.g., ground military, submarines, and air to air missiles). It has an impact on cost, as different operating specifications involve different requirements with respect to portability, reliability, structuring, testing, and documentation. TruePlanning® attributes a value to each operating specification, and this value has a significant impact on development engineering costs. The default value assigned to military ships is 1.60 (midpoint of 1.4–1.8). This number reflects the additional testing and documentation requirements associated with military when compared to commercial ships
	Multiple site development	2.5 Several locations: Two to three active locations within the same country.	The multiple site development value describes communications challenges presented by teams operating in multiple geographic locations. Communication affects productivity and becomes more significant when development personnel work from different sites on the same equipment. This value is a function of the number of and quality of communication between the active locations for the program.

(*Continued*)

Appendix (Continued)

Level	Variable	Input	Explanation
		Poor communication	In this case, there will be three active locations (i.e., the client (DND), the designer (TKMS or BMT), and Seaspan). Federal procurement rules put certain restrictions on the ability of contractors to communicate with federal employees. Since the Government must facilitate communication between the shipyard and the designer, delays or restrictions are likely. Where the communication between three active locations is characterized as poor, TruePlanning® ascribes a value of 2.5.
	Vendor interface complexity	High	The vendor interface complexity describes the degree and intensity of requirements to interface with vendors or subcontractors on the project. It ranges from low to high.
			Technical reviews, audits, and quality assurance requirements in the context of this procurement will be significant as compared with non-military procurements. These requirements will be monitored through a series of "gates" or milestones used to track the progress of the project against its objectives. As such, vendor interface complexity will be high.
	Project complexity factor	75	The project complexity factor is reflective of the planning and oversight activities necessary to successfully manage the project.
		High; Indicates planning and oversight levels typical in a mid-size to large or moderately complex project.	The project complexity factor is used to predict the amount of the oversight and planning required to successfully manage the project. The value of this factor ranges from 0 to 200: a value of 0 will result in no planning and oversight calculations; a value of 50 results in the typical values for planning and oversight activities in a small to mid-size project; and, a value of 100 results in values typical for a large or highly complex project.
			A level of high was selected because of the complexity of managing a military procurement of a unique vessel requiring numerous audit functions and sign-offs.

	Number of vendors	1	Number of vendors indicates the number of outside sources that will be supplying equipment, software, or services. The value of this input influences the effort for system engineering activities. While the exact number of vendors that will be involved in this project is unknown, there will, at the very least, be one: Seaspan. As such, the number of vendors was set at 1. This is a conservative estimate.
Acquisition	Start date	3/1/2014	This date is taken from the most recent Report on Plans and Priorities (RPP).
	Weight of structure	18,469,520 lbs	The weight of structure indicates the weight of the mechanical/structural portion of the equipment. As weight increases, the amount of effort associated with engineering increases, tempered by the impact of increased or decreased technological maturity. Weight increases are also result of increases in effort and material required for prototype development.
	Manufacturing complexity of structure	3.78	The MCPLXS represents a technology index for the structural portion of the equipment and is linked to the operating specification. MCPLXS is a measure of the equipment's technology, its producibility (material machining and assembly tolerances, machining difficulty, surface finish, etc.), and yield. The value for MCPLXS should be determined either through calibration using historical data from past projects or through one of the tools available in True H to guide the user to the right value. In this case, the PBO calibrated using historical data on the Protecteur-class AOR. The MCPLXS returned by that calibration was 3.78.
	Percent of new structure	85%	The percent of new structure represents the amount of new structural design effort based on design tasks which already exist or may have already been completed. The value for the percent of new structure is a cost driver for the development engineering activity for the equipment. The model assumes that new structure requires full development engineering activity and that existing structure requires no engineering at the component level.

(*Continued*)

Appendix (Continued)

Level	Variable	Input	Explanation
			Expert opinion suggests that such design effort will be required whether or not the JSS is based on a pre-existing ship. The adaptation of a pre-existing design to respond to Canadian requirements would involve a significant amount of redesign work.
	Percent design repeat for structure	40%	This input captures the repeated use of design components reflecting the symmetry of the ship's hull. Percent of design repeat is determined by the ratio of redundant hardware to unique hardware. A completely symmetrical ship would result in 50% design repeat. Although the hull itself is symmetrical, some internal components are not, hence, a value of less than 50% repeat.
	Engineering complexity	1.1 New design, within the established product line, continuation of existing state of art.	The engineering complexity value represents a measure of the complicating factors of the design effort as they relate to the experience and qualifications of the engineering design team. Engineering complexity is a significant driver in the development engineering effort.
		Mixed experience, some are familiar with this type of design, others are new to the job.	As skill set and experience decrease or as the engineering challenges increase, the costs for development engineering increase. Development manufacturing and development tooling and test activities also increase with increasing complexity as the engineers and assemblers grapple with implementing and testing prototypes designed by less experienced personnel or within less than ideal design conditions.

			Whether the Government settles on an adapted version of the Berlin-class or clean-sheet design by BMT, the JSS will constitute a new design. Engineering complexity has been returned on this basis, but while making allowances suggesting that the equipment will be part of an "established product line" and a "continuation of existing state of art." Seaspan's experience has been in the field of barges, ferries, smaller commercial ships. The company has very little experience in the class of ships that will be produced. As such, engineering complexity has further been described as "mixed experience" with some of the team being "familiar with this type of design." The PBO is of the view that, based on expert opinion, such assumptions are conservative (i.e., they will return a lower cost estimate). Engineering complexity has no impact on production costs, but does have a non-linear impact on development costs. A 10% increase in engineering complexity will have greater than a 10% increase on development costs.
	Development engineering	Start: 03/01/2014 End: 4/30/2018	These dates are taken from the RPP.[24]
	Production manufacturing	End: 09/30/2019	This date is taken from the RPP.[25]
Other	Labor rates	As per PRICE model	TruePlanning® contains pre-existing labor unit costs for Canadian production. These figures are consistent with data available from the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC and relevant collective agreements.

Appendix D: Current Project Schedule

TABLE D1 Major milestones

List of major milestones	Date
Options Analysis	Fall 2009
Revised Project Approval (Definition)	June 2010
Project Definition Phase Recommenced	July 2010
Project Approval (Implementation)	February 2014
Award of Implementation Contract	March 2014
Initial Operating Capability—First Ship	Spring 2018
Final Operating Capability	Fall 2019

Source: Treasury Board of Canada Secretariat, 2012–2013 Reports on Plans and Priorities: National Defense: Supplementary Tables (2012), online: Treasury Board of Canada Secretariat <http://tbs-sct.gc.ca/rpp/2012-2013/inst/dnd/st-ts04-eng.asp#jss-nsi>.

Appendix E: List of Replenishment Vessels

TABLE E1 List of replenishment vessels

Ship	Navy	Type of ship	Status	Year	Size (tonnes full)
Cantabria	Spain	Fleet Replenishment Ship	In service	Cantabria Laid down[26] 2007 Launched[27] 2008 Delivered July 2010	19,500
Patino	Spain	Fleet Logistic Tanker	In service	Patino Laid down 1993 Launched June 1994 Commissioned[28] June 1995	17,045
Berlin	Germany	Fleet Logistic Tanker	In service	Berlin Launched April 1999 Commissioned April 2001 Frankfurt AM Main Launched January 2001 Commissioned May 2002 Bonn Due to enter service late 2012	20,240
Karel Doorman (JSS)	Netherlands	Joint Support Ship	Laid down Commission date TBD	Laid down June 2011	27,000
Amsterdam	Netherlands	Fast Combat Support Ship	In service	Laid down May 1992 Launched September 1993 Commissioned September 1995	17,040

(*Continued*)

Appendix (Continued)

Ship	Navy	Type of ship	Status	Year	Size (tonnes full)
Lewis & Clark	USA	T-AKE Dry Cargo and Ammunition Ship	In service	T-AKE-1 Launched 2005 T-AKE-2 Launched 2006 T-AKE-3 Launched 2006 T-AKE-4 Launched 2007 T-AKE-5 Launched 2008 T-AKE-6 Launched 2008 T-AKE-7 Launched 2008 T-AKE-8 Launched 2009 T-AKE-9 Launched 2009 T-AKE-10 Launched 2010 T-AKE-11 Launched 2010 T-AKE-12 Launched 2011 T-AKE-13 Due for launch 2013 T-AKE-14 Due for launch 2014	40,298
Henry J. Kaiser	USA	Oiler	In service	T-AO 187 Laid down 1984, Commissioned 1986 T-AO 188 Laid down 1984, Commissioned 1987 Decommissioned 1996 T-AO 189 Laid down 1985, Commissioned 1987 T-AO 190 Commissioned 1987 Decommissioned 1996 T-AO 191 Commissioned 1991	42,000 (42,667.8 long tonnes)

Decommissioned 1997
T-AO 192 Commissioned 1992
Decommissioned 1998
T-AO 193 Laid down 1986,
  Commissioned 1988
T-AO 194 Laid down 1989,
  Commissioned 1991
T-AO 195 Laid down 1987,
  Commissioned 1989
T-AO 196 Laid down 1989,
  Commissioned 1991
T-AO 197 Laid down 1988,
  Commissioned 1990
T-AO 198, Laid down 1989,
  Commissioned 1992
T-AO 199, Laid down 1990,
  Commissioned 1993
T-AO 200, Laid down 1990,
  Commissioned 1992
T-AO 201, Laid down 1991,
  Commissioned 1995
T-AO 202, Laid down 1991,
  Commissioned 1993
T-AO 203, Laid down 1994,
  Commissioned 1996
T-AO 204, Laid down 1992,
  Commissioned 1995

(*Continued*)

Appendix (Continued)

Ship	Navy	Type of ship	Status	Year	Size (tonnes full)
Wave	UK	Auxiliary oiler	In service	Wave Knight Laid down October 1998 Launched September 2000 Commissioned April 2003 Wave Ruler Laid down February 2000 Launched February 2001 Commissioned April 2003	
MARS	UK	Fleet tanker	Planned	Due into service 2016	
Durance	France	Underway replenishment tanker	In service	Meuse (A607) Laid down 1977 Commissioned 1980 Var (A608) Laid down 1979 Commissioned 1983 Marne (A630) Laid down 1982 Commissioned 1987 Somme (A631) Laid down 1985 Commisioned 1990	(A607) 17,900 All variants 18,500
Durance (Success)	Australia	Underway replenishment tanker	In service	Laid down 1980 Launched 1984 Commissioned 1985	17,933
HMAS Sirius	Australia	Replenishment tanker	In service	Launched 2004 Commissioned 2006	37,000 tonnes (deadweight))

Appendix F: Risks Used to Develop Confidence Level

This table provides a summary of the parameters used to generate the confidence level for the JSS estimate. An explanation of the optimistic and pessimistic boundaries of these ranges is provided in the table.

TABLE F1 Range of input variables

Variable	Optimistic	Pessimistic	Explanation of range
Weight of structure	18,469,520 lbs	22,833,440 lbs	It is not possible to predict, with any accuracy, the weight of the ship so early in the design process. However, based on the requirements of the Department of National Defence, the PBO adopted a range reflective of the high and low values of ships of comparable capacity. The PBO adopted the weight of the Protecteur-class as the optimistic (lightest ship) value and then Berlin-class (heaviest ship) as the pessimistic value.
Manufacturing complexity for structure	3.39	4.25	In order to establish the boundaries for the MCPLXS, the PBO ran the calibration of comparable ships (see Table 6). This analysis returned values ranging from 3.39 (corresponding to the Henry J. Kaiser) to 4.25 (corresponding to the Wave).
Percent of new structure	50%	85%	It is not possible to predict the percent of new structure of the ship until a significant portion of the design decisions have been made. However, based on the experience of SMEs, the PBO determined that an acceptable range would be from 50 to 85%. A discussion of the sensitivity of this variable is provided in the methodology section of this report.
Percent of design repeat for structure	50%	20%	It is not possible to predict percent of new structure of ship until a significant portion of design decisions have been made. Assuming perfect symmetry, it is impossible to have a value greater than 50%. Based on historical naval programs, it is unlikely to have a value of less than 20%.
Engineering complexity	0.9	1.1	This variable is calculated by the TruePlanning® application. It is based on a combination of the technology being used in the construction of the ship and the experience of those involved in the design process. The input for the technology is fixed as the JSS will be a new design leveraging existing technology. Based on the current capacity of the designers and the shipyard, the experience levels selected for the model is mixed experience. However, if the designers and the shipyard are able to procure more experienced professionals, the process may be optimized. The optimistic value of 0.9 is based on a scenario where experience designers can be obtained.

Appendix G: Defense Price Escalation

Traditional inflation indexes are not well suited to the defense budgeting process because non-market factors drive defense price escalation.

The Department of National Defence (DND) often procures items that are complex in nature, have unique requirements, and for which there are a limited number of providers. Consequently, many acquisitions, such as the JSS, are multi-year projects.

Allocating and managing the budgets of multi-year projects requires an adjustment for changes in the costs of goods and services over the lifetime of the project. Generically, the term "inflation" is used to describe escalations in cost over time. However, the year-over-year escalation in the cost of defense acquisitions can significantly exceed that of the common inflation indexes because true inflation is only one factor contributing to the cost escalation observed in defense procurements.

The most common measure of inflation—the consumer price index (CPI)—is calculated by measuring the changes in the cost of a basket of consumer goods and services. Although individual goods and services fluctuate at differing rates, CPI has remained relatively stable in recent years at around 2% (Bank of Canada, 2012a). However, CPI it is not an accurate measure of the cost escalation in the defense industry, as the weighted basket of goods and services used to calculate CPI is not representative of the inputs required to build military equipment (Kirkpatrick, 2008). While core CPI is weighted towards household items, the chief inputs for defense equipment are materials (minerals and energy) and labor. Since the increase in the cost of energy has on average exceeded 2% per year (Bank of Canada, 2012b). it follows that defense price escalation can be expected to exceed CPI by some measure.

An alternate method of accounting for the increase in cost over time is the Gross Domestic Product (GDP) deflator. Like CPI, GDP is not representative of the inputs for military procurement. For example, "machinery and equipment" represents approximately 20% of defense spending, but only 8% of GDP (Solomon, 2003). Moreover, defense acquisitions are susceptible to exchange rate fluctuations that are not captured by GDP (Solomon, 2003).

Non-Market Factors Contributing to Defense Price Escalation

Based on the arguments above, it would seem that the logical conclusion would be to create a defense-specific index based on a representative basket of goods, with an appropriate adjustment for fluctuations in exchange rates. However, data on defense procurements

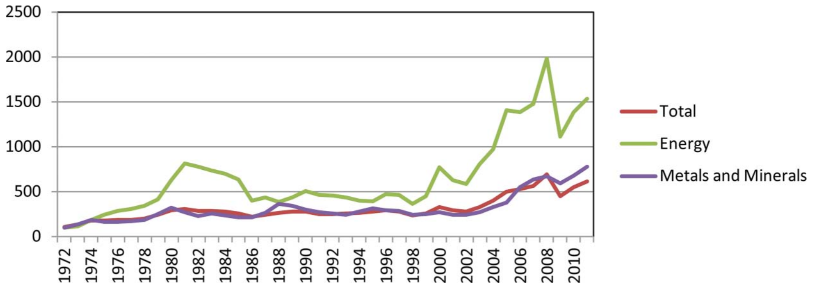

FIGURE G1 Bank of Canada inflation indexes (*source*: Bank of Canada) (color figure available online).

have demonstrated a trend that exceeds what can be explained by price indexes alone (Kirkpatrick, 2008).

In 2006, the RAND Corporation found that escalation in the naval shipbuilding industry over a 50-year period was between 7 and 11% per year depending on the class of vessel (Arena et al., 2006). RAND and other defense economists who have studied this trend have identified two significant non-market factors contributing to this additional escalation: 1) the dynamics of the consumer-supplier relationship; and 2) consumer behavior (Solomon, 2003).

There are few buyers and few suppliers of defense equipment. Many defense procurements, including those of naval ships, require some part or all of the acquisition to be customized, resulting in unique product for which there is only one customer. This relationship, described by economist as a monopsony-oligopoly,[60] results in the consumer paying a premium for goods as the supplier must ensure it is able to recoup its cost and make a profit on a product that has no other potential consumer.

In addition to the premium resulting from the consumer-supplier relationship, there are additional costs incurred as a result of the business processes of departments of defense. The RAND Corporation found that the U.S. Navy, as a customer, had contributed to cost escalation through the use of military standards (Arena et al., 2008, p. 11), increased technological expectation (Arena et al., 2008, p. 11), and ongoing redesign requirements (Arena et al., 2008).

Implications for the JSS Project

The budget envelope for the JSS project was announced in "budget year dollars," meaning that no adjustment will be made to the budget to reflect inflation—defense-specific or otherwise. Figure G2 shows how the $2.6 billion budget has decreased in real terms since the 2010 announcement of the JSS project. Thus, when the JSS Project was re-launched with a new budget of $2.6 billion ($500 million increase over the original project budget), the actual project budget was effectively decreased.

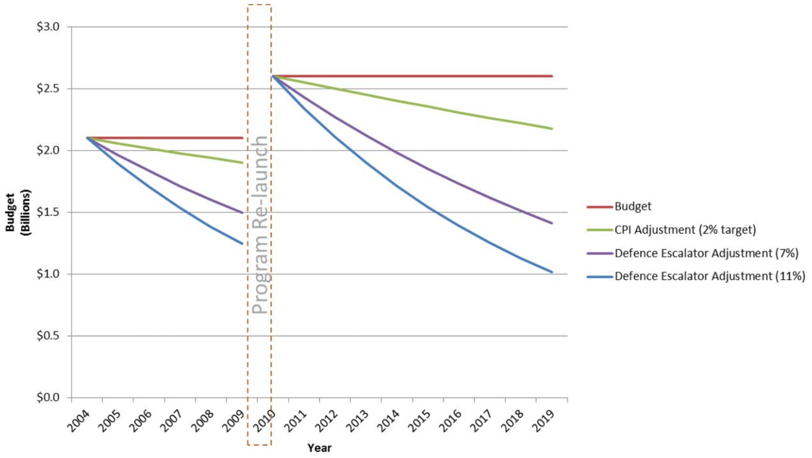

FIGURE G2 Budget discounted for naval escalation factors (*source*: PBO) (color figure available online).