National Defence Défense nationale

Canadian Forces College

Collège des Forces Canadiennes

FLEET COST AND BENEFIT OPTIMIZATION: REPLACE/EXTEND DECISIONS IN THE AGE OF ACCRUAL BUDGETING

Maj S.S. Curley

JCSP 43	PCEMI 43
Master of Defence Studies	**Maîtrise en études de la défense**

Disclaimer

Opinions expressed remain those of the author and do not represent Department of National Defence or Canadian Forces policy. This paper may not be used without written permission.

Avertissement

Les opinons exprimées n'engagent que leurs auteurs et ne reflètent aucunement des politiques du Ministère de la Défense nationale ou des Forces canadiennes. Ce papier ne peut être reproduit sans autorisation écrite.

© Her Majesty the Queen in Right of Canada, as represented by the Minister of National Defence, 2017.

© Sa Majesté la Reine du Chef du Canada, représentée par le ministre de la Défense nationale, 2017.

Canada

CANADIAN FORCES COLLEGE – COLLÈGE DES FORCES CANADIENNES
JCSP 43 – PCEMI 43
2016 - 2017

MASTER OF DEFENCE STUDIES – MAÎTRISE EN ÉTUDES DE LA DÉFENSE

FLEET COST AND BENEFIT OPTIMIZATION: REPLACE/EXTEND DECISIONS IN THE AGE OF ACCRUAL BUDGETING

Maj S.S. Curley

"This paper was written by a student attending the Canadian Forces College in fulfilment of one of the requirements of the Course of Studies. The paper is a scholastic document, and thus contains facts and opinions, which the author alone considered appropriate and correct for the subject. It does not necessarily reflect the policy or the opinion of any agency, including the Government of Canada and the Canadian Department of National Defence. This paper may not be released, quoted or copied, except with the express permission of the Canadian Department of National Defence."

"La présente étude a été rédigée par un stagiaire du Collège des Forces canadiennes pour satisfaire à l'une des exigences du cours. L'étude est un document qui se rapporte au cours et contient donc des faits et des opinions que seul l'auteur considère appropriés et convenables au sujet. Elle ne reflète pas nécessairement la politique ou l'opinion d'un organisme quelconque, y compris le gouvernement du Canada et le ministère de la Défense nationale du Canada. Il est défendu de diffuser, de citer ou de reproduire cette étude sans la permission expresse du ministère de la Défense nationale."

Word Count: 14090

Compte de mots: 14090

TABLE OF CONTENTS

List of Figures

List of Tables

Abstract

Fleet life design has seen inefficient extensions resulting in life cycles which are too long and more expensive than replacing the fleet. When presented with a replace/extend problem set, the Government of Canada appears to be loath to purchase new fleets possibly because of a perception that it is more expensive than extending the life of the current fleet. This tendency can result in reduced capability due to outdated S&T and C4ISR capabilities as well as reduced availability and cost effectiveness related to increasing maintenance demands of aging fleets. One possible approach to addressing this problem set is through definition of a related course of action (CoA) comparison as a means of ensuring that replace/extend decisions are well informed. These CoA are: replace the fleet, conduct a planned fleet life extension, or conduct an unplanned fleet life extension.

If done correctly this CoA comparison sees an examination of the capability or effect which the fleet originally fulfilled and a determination of whether or not the capability requirement has changed; or, if the existing fleet and the number of platforms within it still achieve that defined capability - keeping in mind that the number of available platforms will reduce as the fleet ages.

Utilizing programs such as the Defence Resource Management Information System and historical data on existing and recent fleets, the CAF should be able to estimate what the optimum retirement age of a given fleet will be such that the lowest possible average cost of yearly fleet existence is achieved. Replace/extend decisions must be made early enough to position required resources at the optimum retirement age in support of the chosen CoA. By making replace/extend decisions earlier the CAF will mitigate today's extended procurement timelines.

INTRODUCTION

As operators and end users, Canadian Armed Forces (CAF) Commanders value having platforms available to command. Force multipliers such as the General Dynamics Light Armoured Vehicles (LAVs), Krauss-Maffei Leopard II tanks or Beoing CH-47 Chinooks provide commanders with tremendous flexibility and capability within the modern battlespace. When faced with the prospect of procuring new platforms or deciding to instead extend the life of existing platforms[1], increasingly tight budget constraints and the demanding cost of modern platforms makes it tempting to choose the later. Both choices come with significant expenses. Recent trends displayed in the lengthy life of Canadian Armed Forces (CAF) materiel demonstrate that the Government of Canada (GoC) tends to extend life more frequently than replacing fleets. As a result, the time between purchases of new fleets sees a bow wave of extreme costs followed by decades of prolonged use. This ebb and flow of procurement leads to costs that are too high, procurement programs that are too lengthy and do not facilitate a timely application of Science and Technology (S&T), poor facilitation of regional advantage and military advantage.

A cursory search for procurement metrics or Key Performance Indicators (KPI) nets two significant themes. First, that Canadian military media pundits have a low regard for the CAF and GoC's procurement performance. And second, that there is a significant amount of work and research related to the question of fleet replacement or life extension in civilian fleet management circles. Presumably, the much anticipated Defence Policy Review (DPR) will address the first. The second demonstrates the need for a clear and current approach designed to facilitate the replace/extend decision process for military fleets. In order to do this we must define a fleet life cycle and determine when decisions must be made within that cycle such that

[1]Known within this paper as the replace/extend decision process.

the optimum replace/extend choice will be facilitated. This decision point is dependent on the fleet's optimum retirement age and replace/extend decisions must be made early enough to account for long procurement timelines. This paper's proposed approach to addressing this problem set is through definition of a related course of action (CoA) comparison as a means of ensuring that replace/extend decisions are well informed. These CoA are: replace the fleet, conduct a planned fleet life extension, or conduct an unplanned fleet life extension. There are several key factors related to costly aging fleets, budget constraints, accrual funding, and materiel management, which make this an appropriate time to conduct this examination.

Since 2005 several capital defense purchases have been completed using full accrual accounting. This approach spreads the cost of equipment over its projected life (or a portion of it) as opposed to paying the full cost of the procurement in the year of purchase. The fleets currently in use which were procured using accrual purchasing will in due time come to a natural cross road where they will either need to be replaced or their lives extended. Which naturally leads one to question if that life extension will be financed through accrual budgeting or cash? Because these fleets have not yet reached the end of their designed cycle, in the grand scheme, we are currently in the very initial stages of the age of accrual based procurement. This relatively new approach to funding capital purchases has the potential to make significant changes to the CAF's institutional behaviour. We have not yet faced the problem of an accrual procured fleet reaching the end of its projected life. The Canadian government is on the precipice of an opportunity to leverage this unique circumstance in order to make informed and timely replace/extend decisions which will pay dividends in multiple columns – namely:

survivability, application of Science and Technology (S&T), lethality, range, reduced cost of maintenance, tooling, retention, regional advantage of jobs, and retention of civilian skill sets.[2]

Modern trends of tight budgets and extended procurement cycles with high related costs see fleets' lives extended beyond their ability to facilitate military advantage in a long term loss for short term gain approach. These unresponsive trends are insufficient in providing the CAF the means to successfully operate in the modern battle space and do not responsibly address the fiscal needs of the Canadian public.

As such, the rapid evolution of S&T necessitates an innovative, agile, and responsive procurement system, with the shortest possible procurement cycles, which values the development of capability and military advantage. In order to realize the advantages outlined above, accrual budgeting, and other novel financial and procurement approaches, should be leveraged to replace a fleet whenever necessary vice extending a given fleet's life. In order to determine when it is necessary to replace a fleet there must be a calculation of the optimum retirement age designed into the procurement process. Where possible, in order to flatten the wave of high cost procurement projects; this should be done on a fixed cycle replacing a given portion of a given fleet within an appropriate time frame (for instance 10 percent of the fleet being replaced every year across a ten year time frame).

This paper will argue that the concept of correctly identifying when fleet replacement becomes cheaper than life extension is not fleet specific. The benefits of timely replacement of a fleet apply to a fleet of small arms equally well as it applies to a fleet of capital ships. What differs from fleet type to fleet type – and must be further explored – is the ideal life of each given

[2]Ultimately the desired goal is to maintain a steady rate of fleet building in order to retain capability through the consistent employment of skilled personnel and infrastructure. This pertains to multiple facets of building to include definition of the concept/need, research and innovation, development and design, manufacture, in-service assessment, and so forth.

fleet. A small arms fleet of General Purpose Machine Guns (GPMG) may have a longer projected life (due to its relative simplicity) than a fleet of frigates, Armoured Fighting Vehicles (AFV) or C-17s.[3] As such, the term 'fleet' in this paper is not referring to any specific type of materiel; instead it is in reference to all types of equipment, from 9mm pistols to the Canadian Surface Combatant (CSC). The issues and solutions related to fleet procurement are designed to be applicable – to one degree or another – to all types of fleets.

Though examining all fleet procurement solution sets is outside of the scope of this paper there will be some in depth examinations of specific fleets as models or examples which will illustrate certain criteria potentially applicable to other fleets. Specific procurement approaches must be tailored for any given platform purchase depending on the circumstances at the time within the cycle of that project's development. Peculiarities of politics, industry capability, and economics will always necessitate adjustments being applied to the procurement process. These adjustments must be kept to a minimum wherever possible with significant effort and capability being applied to streamlining procurement, minimizing related costs, leveraging S&T, and maximizing military advantage in order to address the demands of battle within the Future Security Environment (FSE) while facilitating regional advantage.[4]

The FSE will become increasingly complex and display a probability for violence and unpredictability. The FSE comprises multiple extenuating factors such as socio-political alignments related to ongoing and future conflicts, complicated human terrain, demanding physical terrain, as well as non-traditional adversaries with increasingly sophisticated

[3]Robert Walmsley, "Smart Acquisition: The Next Steps," *RUSI Journal: Royal United Services Institute for Defense Studies* 148, no. 2 (April 2003), 27. There is no value in having controls designed for one type of fleet applied to other fleets. Each system will have its own applications of criteria custom designed to optimize that system's advantage. Life length design must be anchored on a sound application of the criteria.

[4]As per the greater definition provided on page 37, the comparison criterion "Regional Advantage" includes factors such as greater incorporation of a product or technology provided from within Canada which will assist with regional development, job retention, industrial competition, or otherwise contribute to the health of the national economy.

capabilities, and access to a wide array of information sources and strategic communications wherewithal. There will likely continue to be significant use of internet proxies and sophisticated use of social media. Non-traditional threats will continue to be increasingly prevalent within the battlespace. Future conflicts and other threats to security will include the use of asymmetric violence launched by major terror groups. Dependent on policy and treaty obligation, these FSE factors have significant potential to contribute to increasing tempo and demand on the CAF and its resources. This makes it crucially important that the CAF develop methods to ensure that a sound replace/extend decision process is developed in order to make efficient decisions at the right time to provide the Canadian populace with value for its limited funds.[5]

In order to demonstrate an approach to defining the moment of optimum fleet replacement and making informed decisions related to that moment, this paper will first define the perceived problems with current replace/extend decisions, it will then briefly outline some possible approaches and factors to be considered when designing a solution, familiarize the reader with accrual versus cash funding, and finally define the CoA comparison model – with related CoA comparison criteria – and design a solution.

DEFINING THE PROBLEM

When presented with the problem of replacing a fleet, the question can be summarized as follows: is it better to minimize overall cost by avoiding the large scale investment of a new purchase? Or, to maximize operational performance by replacing the platform? It is potentially a question of throwing good money after bad versus prioritizing peace of mind. Anyone who owns a car has asked themselves this question at one point or another. With personal vehicles

---

[5] Department of National Defence, A-FD-005-001/AF-003, *The Future Security Environment 2013-2040* (Winnipeg: Chief of Force Development, 2014), 101-103.

the question normally comes up when a major repair involving significant parts and labour becomes necessary (a transmission, differential, or some other key part of the drive train for instance). Is it worth $2000 to repair the vehicle in the hopes of gaining a year or two of payment free use, or is the owner better off investing that $2000 as a down payment on a new vehicle which comes with peace of mind and a significant price tag? For the purposes of civilian fleet management this problem set is portrayed as per Figure 1.1, below.

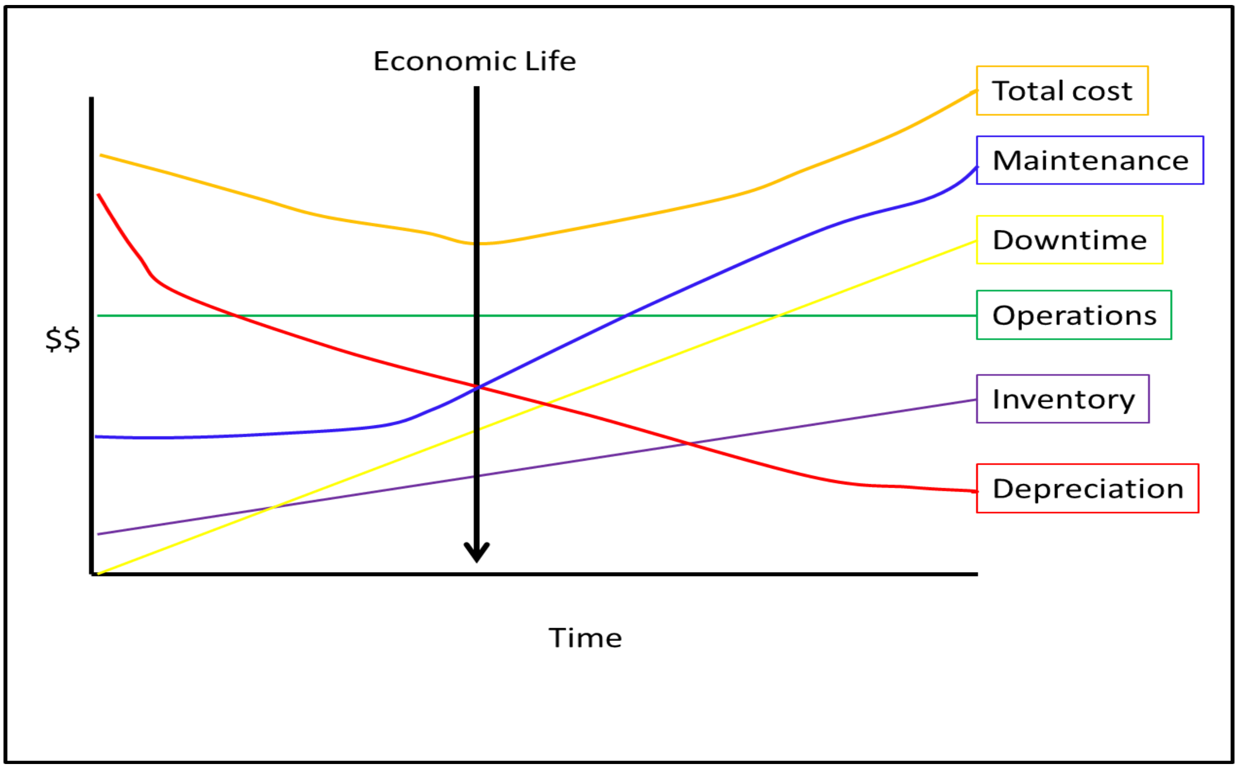

Figure 2.1 -- Civilian Fleet Management
Source: Bibona "Establishing a Cost Effective Fleet Replacement Program.[6]"

Figure 1.1 illustrates the civilian fleet management replacement timing model. Though not necessarily true of a defence fleet, Figure 1.1 assumes an operational demand which is consistent – shown in green. Throughout a civilian fleet's life there is a natural curve to its total

---

[6]See also: Andrew K.S. Jardine, University of Toronto Centre for Maintenance Optimization and Reliability Engineering, "Life Cycle Management." Last accessed 07 April 2017, https://www.fcm.ca/Documents/presentations/2010/workshops/Life_Cycle_Management_EN.pdf

cost per year, shown in orange. This cost declines throughout the vehicle warranty period when the vehicle is most reliable. Throughout this same initial period, the value of the vehicle – shown as depreciation in red – also declines and continues to do so throughout the fleet's life.[7] Cost begins to change when maintenance demands – shown in blue – increase resulting in more downtime (shown in yellow) and less reliability.[8] These increased maintenance demands reflect an increased requirements for spare parts and sustainment inventory capacity, shown in purple.

It is shortly after this upswing in maintenance costs that maintenance intersects with depreciation and the optimum savings or most efficient cost moment occurs (shown as Economic Life in Figure 1.1).[9] Managers need to plan for the replacement of the fleet, at this time, before maintenance and downtime degrade the fleet's capability, increase cost beyond the price of replacement, and have a negative effect on operations.[10] Ideally, the fleet manager will sell the fleet at or near the economic life point in order to leverage the income which the fleet potentially provides in support of purchasing a replacement fleet. Though selling off a CAF fleet to provide income for the purchase of follow on fleets is not always possible (or particularly profitable when compared to the cost of a new fleet) [11] the economic life of a CAF fleet is potentially a suitable decision point for determining the way ahead for that fleet.[12]

---

[7]Timothy J. Beirnes, *Analysis of Fleet Replacement Lifecycle* (West Palm Beach: South Florida Water Management District, 2012), 3. The vehicle will lose half of its value within the first 3 years.

[8]*Ibid.*, 3. These maintenance costs tend to rise dramatically after 240 000 kilometers of use.

[9]*Ibid.*, 7. The economic life occurs when the average annual sum of all ownership and operating costs reaches a minimum.

[10]Mercury Associates, *Fleet Replacement Plan for the City of Prince George* (Prince George: Mercury Associates, Inc., 2014), 2. As opposed to cost comparison some fleet managers use more simplistic approaches with criteria such as age of vehicle fleet in years, or mileage benchmarks to determine when a fleet will be replaced.

[11]Huma Siddiqui, Financial Express, "To Fill Urgent Indian Navy Need, Centre Eyes Canada's Used Sea King Helicopters," last accessed 10 April 2017. http://www.financialexpress.com/india-news/to-fill-urgent-indian-navy-need-centre-eyes-canadas-used-sea-king-helicopters/615283/. There are multiple examples of Canada and other nations selling equipment which they have deemed as surplus or have replaced. There is also potential to secure some funding for Canada or to realize a use for the fleet in support of trusted international partners. As per the article above, India has recently expressed an interest in purchasing a number of Canadian Sea Kings for their navy due to problems with organizing the procurement of their own naval multi role helicopter. See also: David Pugliese. Ottawa Citizen, "India Interested in Used RCAF Sea Kings, According to Report," last accessed 10 April 2017,

Due to the nature of government procurement, the economic life of the vehicle will not be determined by plotting the intersection of depreciation with maintenance and coupling that intersection with the low point in the total cost curve. With civilian fleets the optimum time for replacement occurs when the fleet's value is less than the cost of maintaining it. When it comes to the multi-billion dollar investments in capital defence procurement this model is not as simple and must have a thorough and reasoned empirical process for determining the correct replacement timeline. With military fleets the low point in the total cost curve is not only derived by comparing fiscal cost of maintenance versus replacement but also by identifying the lowest average annual operating costs, and by factoring impacts on military advantage, and the remainder of the five CoA comparison criteria detailed in chapter 5, below. If modeled and executed properly optimum fleet replacement will diminish the current trend of waves of significant cost related to fleet purchase followed by decades of cost related to life extension and maintenance of aging fleets.

There are multiple examples of life cycles extended beyond the point of cost effectiveness and/or military advantage.[13] As detailed in Table 1.1 below, HMCS Protecteur, Canada's west coast Auxiliary Oiler Replenishment (AOR) ship, was commissioned in 1969 with a designed life of 30 years. However, by the time it had a debilitating engine room fire in 2015 it was 15 years beyond its original planned life and it had been only 7 years since its replacement had been contracted. Its replacement project saw preliminary project approval from the Treasury

---

http://ottawacitizen.com/news/national/defence-watch/india-interested-in-used-rcaf-sea-kings-according-to-report. See also: Tristin Hopper, National Post, "Own Your Own Army Convoy: Highlights from the Government's Official Auction Site," last Accessed 14 April 2017. http://news.nationalpost.com/news/own-your-own-army-convoy-highlights-from-the-canadian-governments-official-auction-site.

[12]This would be accomplished by averaging the annual sum of all ownership and operating costs and identifying the year in which these costs would have the lowest average. This year is known as the optimum replacement age.

[13]These examples include the AOR and the Aurora in Canada, and the A-10 in the USAF. "Military advantage" here refers to availability.

Board in 2004 for an Initial Operating Capability (IOC) which would have been eventually realized in 2021 – when the Protecteur would have been 22 years beyond its original life.

Due to the Protecteur's fire and subsequent decommissioning in 2015 there is a significant gap in availability and capability which will be filled by the Interim AOR (iAOR) in fall of 2017, leaving an unplanned capability gap of not less than three years. This Table outlines the problem set which this paper addresses – long procurement timelines, large costs resulting from an ebb and flow of investment[14], extended life cycles resulting in reduced or absent availability and capability. [15] As detailed in the table, the AOR was extended beyond its original life and a replacement project was identified too late to mitigate the potential risks related to today's lengthy procurement timelines which resulted in a capability gap.

Event	**Year**	**Age**	**Life Remaining**
HMCS Protecteur Commissioned	1969	0	30
HMCS Protecteur Life End	1999	30	0
Preliminary AOR Project Approval	2004	35	-5
Letter of Interest Announcement	Feb 2005	36	-6
Pre-Qualification of Potential Bidders	Spring 2005	36	-6
Request for Proposals	Summer 2005	36	-6
Project Definition Contract (two finalists)	2006	37	-7

[14]Arena, Mark V., Irv Blickstein, Obaid Younossi, and Clifford A. Gramach, *Why Has the Cost of Navy Ships Risen? A Macroscopic Examination of the Trends in U.S. Naval Ship Costs Over the Past Several Decades (*Santa Monica: Rand Corporation, 2006), 59, 61.

[15]Steve Durrell, "Shipbuilding Centres of Excellence" in *National Approaches to Shipbuilding and Ship Procurement*, edited by Douglas L. Bland (Kingston: Queen's University, 2010), 109. The GoC has identified this ebb and flow as a problem and the National Shipbuilding Strategy (NSS) includes key related assumptions designed to address the issue. The NSS stipulates that federal ships will be constructed in Canada, as per the Shipbuilding Policy which addresses the regional advantage criteria; that the finite federal demand will be over a 30-year horizon which speaks to the criterion of timeliness; and, finally that government ship-operating departments will load-level the requirements to eliminate the boom/bust cycle.

Effective Project Approval Final Contract Signed	2008	39	-9
Delivery of Initial Ship – POSTPONED	2012	43	-13
Fire Disables Protecteur	Mar 2014	45	-15
Protecteur Paid Off	May 2015	46	-16
GoC Announces iAOR	Nov 2015	N/A	N/A
Interim AOR (iAOR) IOC	Fall 2017	N/A	N/A
Second Queenston Class JSS IOC	Summer 2021	N/A	N/A

Table 2.1 -- Life of the HMCS Protecteur
Source: Richard Gimblett et al., *Vimy Paper 1,* 54.[16]

The Cost of Serviceability / The Cost of Life Extension

To understand the problem set it is necessary to first understand that the cost of life extension is more than just fiscal. As with a civilian fleet's eventual impact on constant operations, life extension, related maintenance, and increased downtime have impacts. This impact on military advantage manifests in two ways – reduced capability related to outdated applications of S&T, and reduced availability due to increased maintenance needs (captured as "down time" in Figure 1.1).[17] The longer a fleet's life is extended, the more likely it becomes that a given enemy has improved the S&T applications to their fleets and rolled out new platforms with greater availability – having a direct impact on the CAF's military advantage.

The fiscal and sustainment impact of a fleet in use beyond its optimum replacement date becomes increasingly problematic and expensive the longer it remains in use. There are several

[16]Table 1 compiled also using data from : Royal Canadian Navy, "Interim Auxiliary Oiler Replenishment Capability," last accessed 8 April 2017, http://www.navy-marine.forces.gc.ca/en/news-operations/news-media-iaor.page.

[17]Edward Keating and Mathew Dixon, "Investigating Optimal Replacement of Aging Air Force Systems," *Defence and Peace Economics* 15, no. 5 (2004), 427, 429. For example, the USAF KC-135 fleet sees required maintenance increase at a rate of 7.62% per year. That said, it grew at a rate of only 2% per year for its first 15 years.

reasons for this to include availability of spare parts which are built to meet specific requirements of that fleet and can take longer to acquire the older a fleet gets. This often results in significant price escalation as the fleet ages and parts become less available and in greater need.[18] While spare parts become increasingly expensive and difficult to come by some costs do not only apply to direct fiscal impact but also apply to military advantage through the impact on availability while the fleet awaits parts and labour. Also, due to reduced capability, the older the fleet becomes, the less likely is it able to effectively operate in today's demanding environments. And, even if it is able to operate, its ability to operate in a relevant and effective manner is inhibited by the fleet's outdated and often irrelevant S&T. For instance, the fleet's firepower may be outdated in comparison to the protective capabilities of the enemy's fleet; or, a Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) capability may no longer be compatible with coalition partners' systems. This C4ISR example can be particularly applicable to criteria related to timeliness of reporting, resolution of imagery, and accuracy of optical suites (in support of mensuration for example).

Significant costs resulting from having a fleet which is not optimally performing extend beyond fiscal impacts and military advantage to have an effect on the health of the organization as a whole. These impacts include: production loss, reduced training and qualification development, maintenance costs in time resulting from increased wear and tear (to include labour/PYs), retention of highly trained and capable personnel due to morale degradation[19] (resulting from maintenance fatigue, frustration, lack of faith/trust), requirements for idle time management or employment of operators who would otherwise be utilizing the fleet, overhead

[18]Ross Fetterly. "Shaping Future Procurement Strategies through Canadian Defence Procurement Reform" in *National Approaches to Shipbuilding and Ship Procurement*, edited by Douglas L. Bland, (Kingston: Queen's University, 2010), 52.

[19]Arena, Mark V., et al., *Why Has the Cost of Navy Ships Risen?...*, 54-55.

costs of increased depot demands, parts depletion and corresponding increased cost of sourcing parts, and tooling.[20] Particularly for large sophisticated multi-nation fleets, the longer a fleet remains in service the more likely that these parts related costs will continue to increase because partner nations will likely no longer be extending the life of the fleet and related fleet subscriptions get smaller by the year. For the CF-18 for instance, Public Services Procurement Canada has assessed that fleet extension to 2030 would result in Canada being the only nation still using the fleet, making parts too expensive to entertain the notion of such an extension because related costs are too high.[21]

As a further example of costs related to parts and tooling, of the A-10's almost 10000 parts, 60% of them are specifically unique to the A-10 with the majority of the remaining parts being specific to aircraft in general (such as titanium bolts).[22] As a result, these costs can be further exacerbated by unforeseeable eventualities such as Business /Corporate failure (literally going out of business or altering service due to mergers[23]), and other unpredictable, market dependant fluctuations in service provision and sustainment. This can result in very long time lines for sourcing parts which in turn sees vehicles being off road. In extreme cases some such vehicles have been out of service for more than 300 days – often because original parts manufacturers may no longer make required parts resulting in a need to seek a new manufacturer with all of the tendering and procurement problems and time demands that that entails.[24] It is possible to cost effectively extend the life of a fleet. But, for the reasons outlined above, in order to do this without incurring increased cost (when compared to fleet replacement), there must be a

[20] Shawn R. Jones and George A. Zsidisin, "Performance Implications of Product Life Cycle Extension: The Case of the A-10 Aircraft." *Journal of Business Logistics* 29, no. 2 (2008), 189.

[21] Public Services and Procurement Canada, "Summary Report – The Evaluation of Options for the Replacement of the CF-18 Fighter Fleet," last accessed 14 April 2017, https://www.tpsgc-pwgsc.gc.ca/app-acq/amd-dp/air/snac-nfps/eorfcf18-eorcf18ff-eng.html.

[22] Shawn R. Jones et al., "Performance Implications of Product Life Cycle Extension…, 191.

[23] Arena, Mark V., et al., *Why Has the Cost of Navy Ships Risen?...*, 53.

[24] Shawn R. Jones et al., "Performance Implications of Product Life Cycle Extension…, 95.

significant investment in sustainment capabilities such as maintainers, depot space, parts stockpiling, and potentially alternate means of achieving a capability or effect should the fleet be largely unavailable.

For example, in 1997 the United States Air Force (USAF) A-10 fleet was approaching its designed life termination after having flown 6000 flying hours per platform (with the first one having reached this benchmark in 1994 and the last in 2000).[25] With constrained budgets, reduced numbers of planned F-22 to take over the Close Air Support role for the Army, and delays in production of the F-35, the USAF decided to extend the life of its A-10 fleet to a platform retirement of 2028. This was done to reduce costs and avoid the requirement to purchase a new fleet to fill the role of the A-10. However, the USAF did so without correctly planning for the provision of a robust supply and sustainment base to support the fleet's life extension. As such, the decision to extend the A-10 life turned out to be more costly than replacing the fleet. This is determined by examining the A-10 fleet's costs from 1998 to 2004 – a period beyond the originally designed service life of the fleet.[26]

Figure 1.2 is a graphic representation of the cost of extending the life of the A-10 past the originally designed retirement of 1997, compared to the cost of a replacement. Significant costs were incurred between 2007 and 2012 when the fleet required a replacement wing ranging between $700 000 to $1.3 million (2008 USD) per wing. Additional costs from multiple years of use leading to airframe fatigue and a reduced supplier base have resulted in costs which are

[25] *Ibid.*, 197.

[26] This was found by comparing aggregate performance quantitative data using a fleet of 283 platforms in 1994 with 131 aircraft in 2004 and saw the mission capable rate of the fleet reduced by 16% when comparing the two years. *Ibid.*, 200 to 203. A similar conclusion was drawn with the C5 fleet, see: Edward G. Keating, Don Snyder, Mathew Dixon, and Elvira N. Loredo. *Aging Aircraft Repair-Replacement Decisions with Depot-Level Capacity as a Policy Choice Variable* (Santa Monica: Rand Corporation, 2005), 27-42.

greater than the procurement of a new fleet would have been, with a potential difference of over $2 billion.[27]

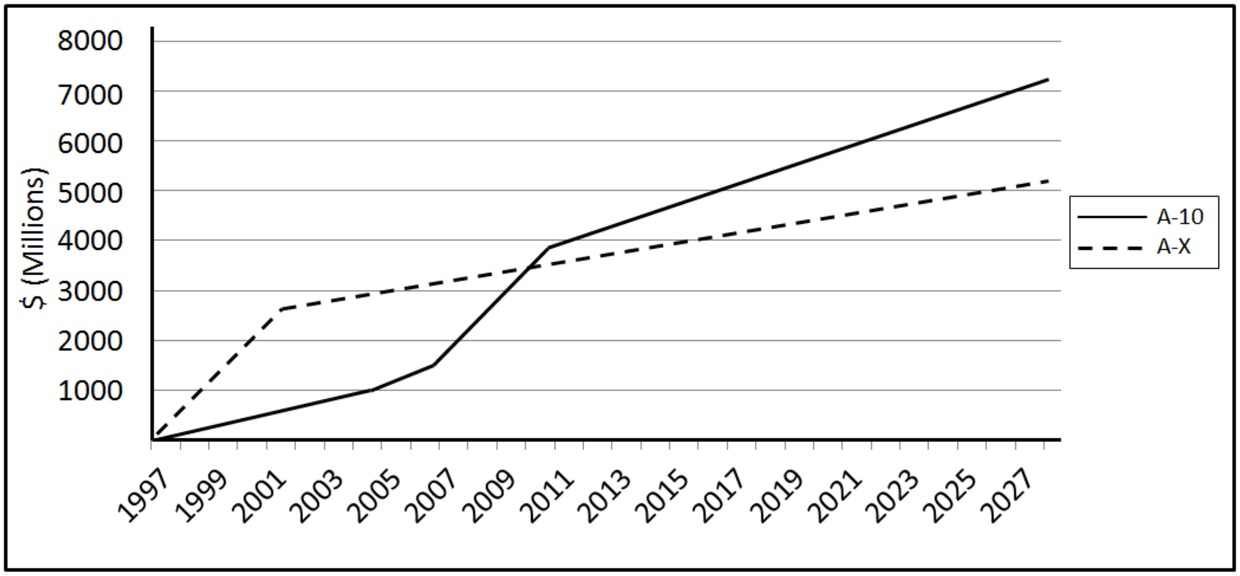

Figure 2.2 – Cumulative Life Costs of the A-10 versus A-X
Source: Shawn R. Jones and George A. Zsidisin, "Performance Implications of Product Life Cycle Extension: The Case of the A-10 Aircraft," 197.

Throughout the period of 1994 to 2000, the A-10 mission capability rates[28] show significant numbers of vehicles out of service due to awaiting parts or labour. The further a given life is extended the more prevalent these trends become ultimately resulting in increases in the cost of operating the platform per operational hour. Cost per flying hour also increased from $1800 in 1994 to over $3000 in 2004.[29] These costs can be reduced by planning for the entire life cycle of the fleet- to include parts production and stockpiling – and then ensuring operational performance by sourcing parts and sustainment provision equal to the life (regulated or extended) of the platform. If the life is extended beyond the reliable sourcing of parts and sustainment then the platform will not perform as required and the costs (as outlined above) will

[27] Shawn R. Jones et al., "Performance Implications of Product Life Cycle Extension…, 204-205.

[28] Capability rates encompass how often an aircraft is not serviceable, how quickly and effectively it's repaired, and to what degree spare parts are stockpiled, in order to provide a metric for the health of the fleet.

[29] Shawn R. Jones et al., "Performance Implications of Product Life Cycle Extension…, 200 to 203.

grow beyond the cost of replacing the fleet. This will happen while the military advantage realized through the operation of the fleet is proportionately reduced (due to a reduction in capability and availability) – a prospect which comes with a significant amount of risk when it is applied to the modern battle space.

Beyond the A-10 there are other case examples which prove that simple life extension without directly solving parts supply issues will result in a platform with insufficient operational relevance and capability.[30] A 2009, Defence R&D Canada study on the CP-140 Aurora long range patrol aircraft found that the cost of operating an Aurora was $5087 per flying hour in 1996, and that this figure had climbed to $11758 per flying hour in 2005. Annually, per aircraft, this cost grew from $2.84 million in 1998, to $4.98 million in 2007.[31] This growth rate of Operations and Maintenance (O&M) costs can be applied to the future with relative certainty and becomes exponential if delayed too long.

Costs are not only fiscal in nature. The impact of an aging fleet on military advantage is significant. The operational availability of the Aurora fleet was less than 25% in 2004 and less than 20% in 2005.[32] As graphically displayed in Figure 3, these factors resulted in an R&D Canada conclusion that the optimum retirement age for the Aurora fleet was when the platform was 15 years old (1995). If the Aurora were to have been retired in 2015 (when it was 35 years old) the total loss (compared to replacing the fleet in 1995) is $63 million per aircraft with a total

---

[30]Such as the Sea King, Aurora, and AOR.

[31]A. Sokri. Defence R&D Canada, DRDC CORA TM 2009-027, *An Economic Evaluation for CP-140 Aircraft Replacement* (Ottawa: Centre for Operational Research and Analysis, 2009), 1. This represents an annual increase of 7.87% in 1998 climbing to 26.13% in 2005 and an overall fleet cost increase of 84% from 1998 to 2007, and is coupled with an increase of 138% in maintenance person hours per flying hour.

[32]*Ibid.*, 5. Operational availability is defined as the proportion of observed time that a group of aircraft is in an operable state (not undergoing maintenance). This lack of availability is a direct result of the Aurora Incremental Modernization Project (AIMP) which made the annual cost per Aurora $12.5 million per asset. The AIMP was required to upgrade the fleet from its 1960's technology related to items such as radios, communications systems, computers, radars, and other sensors. Defence R&D found that AIMP accounted for higher O&M costs but that the project did not influence the optimal retirement age of the fleet. See also: National Defence and the Canadian Armed Forces, "CP-140 Aurora Fleet Modernization and Life Extension," last accessed 27 April 2017, http://www.forces.gc.ca/en/business-equipment/procurement-projects/aurora-cp-140.page

loss of $1.14 billion across the 18 x CP-140 aircraft fleet.[33] The average annual operating cost is of the CP-140 Aurora fleet is graphically displayed in figure 1.3, below.

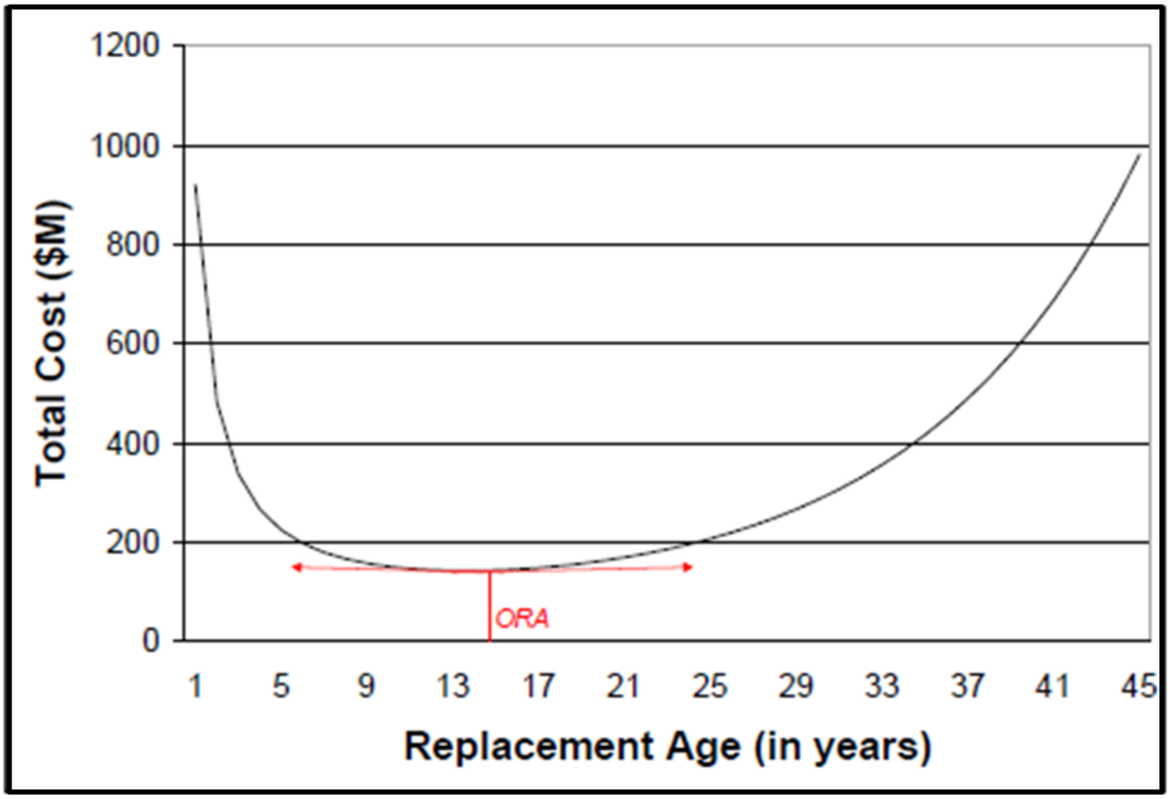

Figure 2.3 – Optimum Replacement Age for the Average CP-140 Fleet
Source: A. Sokri. *An Economic Evaluation for CP-140 Aircraft Replacement*, 13.

Figure 1.3 shows that the optimum replacement age – calculated in this case using a cost model which includes operational availability – is when the average CP-140 platform was 15 years old. Every additional year of use produces added costs which eventually will grow exponentially. The fleet is currently in its 37th year of use. If the optimal retirement age is calculated using strictly fiscal cost then the optimal retirement age can extend to between 29 and 37 years.[34] Between the AIMP and the Aurora Structural Life Extension (ASLEP), which will

[33] *Ibid.*, 13. The Aurora originally cost $37.3 million dollars per platform in 1980. The CP-140A Arcturus cost $79.7 million per platform in 1993.
[34] *Ibid.*, 13, 17.

replace the wings and horizontal stabilizers, the fleet is slated to be in use until 2030 with no replacement project yet funded[35] – making the fleet nearly optimally expensive.[36]

As seen with the AOR, if an optimum fleet replacement date is not identified and planned for there can be a capability gap with associated risks which will have to be removed, mitigated, avoided, or accepted. As with the A-10 and the CP-140, if not planned appropriately refurbishment and continued maintenance can be more costly than replacement.

POSSIBLE APPROACHES, FACTORS and CRITERIA

It is not always necessary to replace a fleet one-for-one. When determining whether or not to replace a fleet of vehicles such as the Coyote Reconnaissance Vehicle (CRV) an important consideration or factor is the number of replacement vehicles which are required to achieve the desired capability encompassed in the old fleet[37] vice an exchange of the number of vehicles. For instance, when considering an appropriate replacement platform for the CRV the armoured vehicle comparison criteria of mobility, firepower, and protection (MFP) must be considered along with the capabilities encompassed within the CRV's surveillance and reconnaissance role – namely its C4ISR capabilities. A modern replacement option may have a more powerful surveillance suite with updated colour day cameras and higher fidelity night cameras capable of accurate laser designation. The suite could also have an updated radar capable of identifying targets at a wider range allowing for greater standoff from target areas. The vehicle could have updated high capacity computers and communications suites, larger calibre weapons with

[35]Daniel Leblanc and Steven Chase, The Globe and Mail, "Sajjan to Lower Expectations for Future Military Purchases," ast accessed 6 May 2017, http://www.theglobeandmail.com/news/politics/sajjan-to-lower-expectations-for-future-military-purchases/article34882029/. See also: National Defence and the Canadian Armed Forces, "Aerospace Systems," last accessed 5 May 2017, http://www.forces.gc.ca/en/business-defence-acquisition-guide-2016/aerospace-systems.page.

[36]National Defence and the Canadian Armed Forces, "CP-140 Aurora Fleet Modernization and Life Extension," last accessed 27 April 2017, http://www.forces.gc.ca/en/business-equipment/procurement-projects/aurora-cp-140.page. Optimum expense according to figure 3 will be achieved in 2034.

[37]Edward G. Keating, et al. *Aging Aircraft Repair-Replacement Decisions…*, 9.

accurate fire control systems, capacity to carry more troops and use less fuel.[38] Such updated capabilities could allow a smaller fleet to replace a larger one making the number of new platforms required to replace the old fleet a decisive determining factor in deciding whether to replace a fleet or to extend its life.[39] This is important when determining if and when a fleet should be replaced which impacts multiple decision criteria to include cost effectiveness and innovation.

This was seen in 1993 when the Lynx Armoured Reconnaissance Vehicle was replaced by the CRV. The Lynx was a relatively small 9 tonne, 3 crew, tracked vehicle which was highly mobile and armed with a .50 calibre machine gun as well as a pintle mounted 7.62 mm GPMG. By 1993 the Lynx had been in service for 25 years and as such it lacked modern C4ISR capabilities.[40] The CRV on the other hand was a 14.5 tonne, 4 crew, wheeled vehicle armed with a 25mm chain gun and two x 7.62 GPMG. But beyond armaments the CRV had a modern and very capable surveillance suite to include optics, day and night cameras, and a radar making the vehicle significantly more capable in both firepower and surveillance. These more modern C4ISR capabilities gave the CRV greater stand-off and range, allowing fewer vehicles to accomplish greater tasks – or as with the CRV, allowing reconnaissance squadrons to cover more ground in support of their brigades. The Lynx was therefore appropriately replaced due to its age, limited firepower, and lack of modern surveillance capability. Had the life of the Lynx been extended into the modern battlespace it would potentially have been of limited use due to a lack of available parts.

---

[38]Wei Feng and Miguel Figliozzi, "Vehicle Technologies and Bus Fleet Replacement Optimization: Problem Properties and Sensitivity Analysis Utilizing Real World Data," *Public Transport* 6 (2014), 149-150.

[39]Edward G. Keating, et al. *Aging Aircraft Repair-Replacement Decisions…*, xiii, 7-10. Conversely, if a greater number of the new platform would be required to replicate the capabilities of the platform being replaced then life extension and/or modification of the existing fleet may be the cheaper option.

[40]For more information on Canadian historical armoured vehicles see: Ed Storey, "The Success of the Light Armoured Vehicle," *Canadian Military History* 20, no. 3 (Summer 2011), 77-80.

Many of the problems related to the cost of extending the life of a fleet can be addressed so long as the fleet is not so old that parts are now obsolete (due to manufacturers no longer producing them) or that the platform no longer has a relevant capability within the modern battle space. As detailed in CoA 2 below, parts obsolescence and maintenance logistics supportability[41] must be incorporated into a plan to extend the life of a fleet or the cost of life extension will outstrip the cost of replacing that fleet.

Long term performance based contracts are a possible approach to solving this portion of the problem set. In this example the corporation providing the platform is contracted to maintain the fleet and is responsible for providing the related parts. The contract includes provisions for fleet operating percentages – for example, 80 percent of the fleet must be operational at any given time. This example assumes that the remaining 20 percent of the fleet is at a maintenance facility where it is in labour, awaiting labour, or awaiting parts prior to returning to its operational unit for continued service. Failure to meet agreed upon levels of operational service (through the failure to maintain appropriate levels of spare parts and skilled labour) results in some sort of fine or a reduction in government reliability rating which would negatively affect future contract competitiveness. This approach reduces the level of uncertainty for both the DND and the fleet provider – this is particularly true when the platform is highly specialized and technical in nature where industry savings of 3 to 20 percent can be realized.[42] The end result can be a dramatic improvement in availability and in cost.[43]

[41]William Weston C. "CF-18 Systems Life Extension: Need or Nonsense?" *Canadian Defence Quarterly* 27, no. 2 (Winter 1997), 15.
[42]Shawn R. Jones et al., "Performance Implications of Product Life Cycle Extension…, 206.
[43]M.K. Painter, M. Erraguntia, G.L. Hogg, and B. Beachofski, "Using Simulation, Data Mining, and Knowledge Discovery Techniques for Optimized Aircraft Engine Fleet Management." *Simulation Conference* (Winter 2006), 3.

Betterment as Opposed to Life Extension

In order to ensure that innovation and military advantage are facilitated, it is important to design fleet life to include a planned and funded betterment upgrade.[44] This will ensure that the fleet is relevant and addresses the demands of the FSE by providing an opportunity to improve the fleet's survivability, lethality, C4ISR capabilities, and TIP compatibility. Whether or not betterment is likely to be required should be determined by fleet and will be more applicable to technologically sophisticated platforms. CAF fighters and the Royal Canadian Navy's CSC will likely need a period of betterment to extend the value and relevance of these very expensive fleets. These upgrades would be conducted in areas such as tech heavy weapons and communications suites and will specifically target the relevance and application of systems and armaments to ensure survivability and lethality.[45] As we are now seeing with the fielding of the F-35 fleet this is particularly applicable to the communications suites in the CF-18.

Without a concerted, targeted effort to maintain capability, interoperability with defence partners (ABCA and NATO) can become degraded. Planned betterment and phased replacement allow this degradation to be avoided or mitigated. "Modern operations demand agile communications with a wide range of capabilities, just as new or upgraded electronic warfare systems must take full account of a hostile, and increasingly complex, electronic environment.[46]" As a result, betterment programs specific to fighter aircraft could include such key upgrades as electronic jamming systems designed to counter hostile transmissions, updated missile approach

[44]This process is not unusual. It is currently being conducted on the Halifax-class frigates along with several other platforms across the CAF as seen at the following site: National Defence and the Canadian Armed Forces, "Halifax-Class Modernization and Frigate Life Extension," last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/halifax-frigate.page. Planning for betterment is a key part of the proposed life model in the solution portion of this paper. The Halifax-class modernization includes a new combat management system, new radar capability, new electronic warfare systems, upgraded communications and missile systems. These upgrades cost $4.3 billion and scheduled to be complete early next year.

[45]William Weston C. "CF-18 Systems Life Extension…, 14.

[46]*Ibid.*, 115.

warning, radar warning receivers and other key defense enablers with rapid improvements resulting from applied R&D.[47]

Expenses related to the process of improving a capital asset fleet during the fleet's life (as opposed to extending the life longer than originally planned) are known as "betterments.[48]" As stated above, betterments can be done to improve serviceability, interoperability, or to reduce operating costs related to parts and maintenance. These costs are not necessarily foreseeable but they should be accounted for and financed (to the extent possible) to add to the value of the asset.

Demographics and Finance in the Future Security Environment

When determining whether or not to extend the life of a fleet fiscal constraints are often a key determining factor. As seen with the A-10, when determining whether or not to extend fleet life fiscal constraint is frequently quoted as being a reason for choosing life extension, vice fleet replacement.[49] Due to demographic trends, these budgetary constraints will likely become more severe in the coming decades, making it crucially important that the CAF plan for the most fiscally prudent course of action wherever possible.

One such trend is aging population: "as the aging population will account for about 50% of the population by 2050 and the traditional working age population (18-64) will peak that year. This will put upward pressure on spending and downward pressure on revenue.[50]" This becomes increasingly disconcerting when one considers that Canada's traditional approach to addressing demographic issues is to increase immigration – an approach which may not work in the coming decades as population shrinkage and related demographic issues will be a worldwide

---

[47] *Ibid.*, 15.

[48] Ross Fetterly, and R. Groves. *Accrual Accounting and Budgeting in Defence*. (Kingston: Queen's University, 2008), 32.

[49] Shawn R. Jones et al., "Performance Implications of Product Life Cycle Extension…, 204-205.

[50] Binyam Solomon, "An Economics Perspective on a Defence Industrial Policy" in *2010 Canadian Defence Industry at a Crossroads*, ed. Craig Stone (Kingston: Queen's University, 2010), 12.

phenomenon by the end of this century.[51] Though some of this will likely be offset by increasing the retirement age of workers, aging population trends will see significant inter-ministerial competition for budget expenditures due to demands related to initiatives such as pensions, health services, and minimum guaranteed incomes.[52]

These budget tightening conditions exacerbate an acquisition system which over the years has become so dysfunctional that procurement cycles can stretch in excess of 15 years (as with the AOR) from government approval to operational employment by the CAF.[53] These long procurement time frames and corresponding life cycles are often facilitated through the life extension of the fleet in service. Such extensions can result in a degradation of capability and/or additional stress on maintenance systems or can necessitate stop gap purchasing of fleets – such as with the recent announcement of the purchase of 18 x Boeing F/A-18 Super Hornets. The Super Hornet purchase is designed to augment the fleet of 79 remaining upgraded F/A-18 AM/BM Hornets which were originally purchased between 1982 and 1988 as part of a total procurement of 138.[54] The now mixed fleet of Hornets and Super Hornets will remain in service

---

[51]Government of Japan, "Regionalism Revitalizes Japan" last accessed 03 November 2016. http://www.japan.go.jp/initiatives/regionalism_revitalizes/index.html. This trend assessment is a result of increasing prevalence of sex education, increased female employment and capacity building, contraception, and diminishing mortality rates reducing the need for large families. See also: Strategic Trends Program, *Global Strategic Trends – Out to 2045* (Shrivenham: Development Concepts and Doctrine Centre, 2014). 4.

[52]Hugh D. Segal, "Finding a Better Way: A Basic Income Pilot Project for Ontario," last accessed 28 April 2017, https://files.ontario.ca/discussionpaper_nov3_english_final.pdf. See also: Andew Coyne, National Post, "How a Guaranteed Minimum Income Could Work in Canada," last accessed 28 April 2017, http://news.nationalpost.com/full-comment/andew-coyne-how-a-guaranteed-minimum-income-could-work-in-canada.

[53]Richard Gimblett, Paul Manson, Howard Marsh, Pierre Lageux, Peter Cairns, and Brian MacDonald, *Vimy Paper 1: Creating an Acquisition Model That Delivers*, (Ottawa: Conference of Defence Associations Institute, 2006), 6, 15. Compare this 15 year example with a five year complete cycle for the F-18/A Hornet which was approved by the Trudeau government in 1977 with initial delivery in 1982 and it shows that somewhere in the last 35 years bureaucratic mission creep has set in, greatly expanding the time required to field new procurements. Kim Richard Nossal, "Late Learners: Canada, the F-35, and Lessons from the New Fighter Aircraft Program," *International Journal* 68, no. 1 (Winter 2012/2013), 168.

[54]William Weston C. "CF-18 Systems Life Extension…, 13. It is interesting to note the extent to which availability of the fleet has degraded throughout its life – reducing in number from an original fleet of 138 platforms in the 1980s, to less than 80 remaining today. Presumably this is not a result of fewer fighters being currently required to fulfil the fleet's original role.

together until the Hornet fleet is phased out between 2017 and 2023 and presumably a new fleet is procured which may or may not be the F-35.[55] The CF-18 Hornet will therefore have seen over 40 years of service. Tightening these time frames in support of military advantage necessitates the development of cost effectiveness as a key CoA comparison criterion (as detailed on page 31).

In addition to demographics, tightening budgetary constraints will become a greater concern as large sophisticated fleets and their weapon systems become more expensive to produce.[56] According to a RAND corporation study related to US Naval costs over the past four decades "the cost of military equipment is increasing more rapidly on a sustained basis than the rate of general inflation and this is a perennial obstacle to maintaining the purchasing power for defence capital equipment.[57]" These expenses are directly related to changes and improvements in factors such as technology, profile or stealth, weapon complexity in target acquisition and tracking, and survivability in various fleets.[58]

This is important because capable, modern, technologically advanced forces are most likely to be able to achieve relative superiority through an economy of effort. To reduce risk and minimize potential cost in human lives, the small economy of force units fielded in the FSE will need technically sophisticated systems in order to achieve superiority, have a desired effect, meet their objectives and end states. This applies to conventional forces as well as Special Operations

[55]Defence Industry Daily, "Canada Preparing to Replace its CF-18 Hornets," last modified [or accessed] 09 February 2017. http://www.defenseindustrydaily.com/canada-preparing-to-replace-its-cf-18-hornets-05739/

[56]Younossi, Obaid, Mark V. Arena, Robert S. Leonard, Charles Robert Roll, Jr., Arvind Jain, and Jerry M. Sollinger, *Is Weapon System Cost Growth Increasing? A Qualitative Assessment of Completed and Ongoing Programs (*Santa Monica: Rand Corporation, 2007) 33-35, 44. It is important to note that defence systems are not the only systems increasing in sophistication and expense – it is true of many complex projects which will place increased pressure on budgeting across a wide spectrum of ministries, agencies, and public works.

[57]Ross Fetterly. "Shaping Future Procurement Strategies…, 55.

[58]Arena, Mark V., et al., *Why Has the Cost of Navy Ships Risen?...*, 42-43.

Forces (SOF) and has an immediate impact on procurement as sophisticated systems, capabilities and training are required to facilitate relative superiority in order to minimize risk.[59]

Tighter budgets and increasingly costly systems will have to be applied to meeting Canada's defence obligations in a complex and demanding battlespace. The FSE will become increasingly complex and display a continued probability for violent acts and unpredictable terror which will in turn potentially result in periods of intense combat and high contingency operations tempo.[60] These characteristics result from multiple extenuating factors such as environment change, socio-political networks related to ongoing and future conflicts, difficult physical, social and human terrain, and non-state threats with sophisticated technical communications capabilities providing significant access to information. Both traditional and terror related threats and will likely be prevalent and present significant challenges. These challenges will encompass the use of asymmetric violence launched by adversarial international terror groups which will be facilitated by science and technology.[61] Devising and resourcing defence policy and approaches designed to respond to these challenges will likely be an expensive process necessitating a sound and reasoned approach to replace/extend problem sets.

Key determinants of a modern military's ability to fight, survive, and win - or otherwise impose their will on the enemy - include increased lethality, range, surveillance capabilities, counter IED survivability, as well as other factors of manoeuvre, firepower, and protection.[62] Arguably these increases in capability and corresponding costs are a direct result of

---

[59]William H. McRaven, "The Theory of Special Operations" (Thesis and Dissertation Collection, Naval Post Graduate School, 1993), 5.

[60]Office of the Under Secretary of Defense (Acquisition, Technology and Logistics), Property and Equipment Policy Office, "Military Equipment Useful Life Study – Phase II: Final Report" (Washington: Office of the Secretary of Defense, 2008), 5.

[61]Department of National Defence, A-FD-005-001/AF-003, *The Future Security Environment…*, 63, 101-103.

[62]Stephen Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle*, (Princeton: Princeton University Press, 2004), 197. Biddle lists the following technological changes as being revolutionary: increased lethality of precision guided weapons, increased range of deep strike air and missile systems, and increased ability to gather and process information. All of which involve expensive systems.

technologically sophisticated developments within the last century to include progress related to three laws of computing and their effect on research, transmission, and capability in general: Moore's Law which states that computing capacity doubles every 24 months,[63] Fiber Law which states that communication capacity doubles every 12 months and, Kryder's Law which states that storage capacity doubles every 12 months.[64] These factors are all research and development intense which see rapid if not exponential increases in capability in relatively short periods of time necessitating an equally rapid ability for the CAF to adapt to or incorporate updates. In short, "the possession and application of sophisticated science and technology may perhaps be the major enabling factor contributing to success in the battlespace.[65]" This is why it is important that a procurement model plan for and fiscally account for betterment in certain fleets. The planned betterment process will reduce the drastic ebb and flow of procurement waves and associated costs by regulating and flattening intervals of investment which will see dividends in military advantage through applied incorporation of S&T, and cost effectiveness through high tech job retention and capability gap reduction or management.

While complex weapon systems grow in expense at a rate higher than inflation,[66] common household electronics have become cheap and easily available enablers. "The increased affordability of sophisticated, cutting edge technologies such as three dimensional (3D) printers,

---

[63]MIT Technology Review, "Moore's Law is Dead. Now What?" Last modified [or accessed] 20 February 2017, https://www.technologyreview.com/s/601441/moores-law-is-dead-now-what/. As detailed in this source, arguably the rate at which computing capacity is growing will decline due to the realities of finite space within which silicone transistors can be placed on a chip. That said, innovative use of emerging technologies shows no sign of abating as a result and modern computing capability demonstrates potential capacity beyond its current use.

[64]Chip Walter, Scientific American, "Kryder's Law," last accessed 6 May 2017, https://www.scientificamerican.com/article/kryders-law/. Although technological advances described by these laws have made tremendous progress over the last 50 years, the potential impact of (and costs related to) quantum computers within the next decade could be exponentially greater, see: Russ Juskalian, MIT Technology Review, "Practical Quantum Computers," last accessed 28 April 2017, https://www.technologyreview.com/s/603495/10-breakthrough-technologies-2017-practical-quantum-computers/.

[65]Department of National Defence, A-FD-005-001/AF-003, *The Future Security Environment…*, 64.

[66]Arena, Mark V., et al., *Why Has the Cost of Navy Ships Risen?...*, 1. Weapon costs have typically grown 5% annually with advanced systems such as tactical aircraft growing at 10%.

electric vehicles, and smart communications devices benefits [sic] large parts of the population.[67]" This affordability of technology has a significant impact on both state and non-state actor operations. For instance: As stated in the FSE, "socio-technical networks will continue to facilitate the organization of protests.[68]" The potential use of social network sites and cellular applications (apps) applies not only to protests but to direct action. Social networks will likely play an important C4ISR role prior to and during terror attacks. They will likely also have a significant role immediately following attacks when they would be used in an influence activities capacity through the uploading (often in real time) of audio and video to social media sites and apps. C4ISR like use of apps and other social media will be used to coordinate the rapid mobilization of players, as well as the execution of attacks and to build a common operating picture in support of those attacks.[69] Meanwhile, CAF responses to those attacks will remain encumbered by doctrinal Tactics, Techniques, and Procedures (TTPs) and common relatively slow uses of practiced Command and Control (C2) processes. This will continue until such time as a responsive modern reaction to attack is devised and practiced. These means must address the capabilities which S&T and modern C4ISR give the enemy. In order to fight, survive, and win in the FSE the CAF must have a system in place to ensure that its limited resources are being applied to the procurement cycle in such a way that Canadian and allied significant S&T capabilities are being leveraged to enable the realization of relative superiority at the place and time of our choosing. This makes innovative S&T application of modern technology – as well as timeliness – decisive criteria for the judgement of procurement processes.

[67]Department of National Defence, A-FD-005-001/AF-003, *The Future Security Environment…*, 67.
[68]*Ibid.*, 70.
[69]*Ibid.*, 67, 70-71.

The difficulty lies in finding the balance between procurement cycles utilizing accrual purchasing and agile, flexible procurement (keeping in mind that accrual purchase can limit availability of funds). Procurement approaches must be responsive enough to incorporate betterment in order to facilitate military advantage. Emerging technologies can be incorporated into procurement through either phased cyclical introduction of percentages of fleet replacement or through planned betterment mid-life. Both of these approaches should be incorporated into a fleet's life-cycle where necessary in order to maximize benefits related to innovation, reduce financial and military advantage costs, and to avoid capability gaps.

FLEET COSTS, ACCRUAL and CASH BASED ACCOUNTING

The 2010 announcement of the purchase of 65 F-35 Joint Strike Fighters came with a price tag of $9 billion for the fleet and a further $7 billion for fleet sustainment and $9.6 billion to operate the fleet across a 20 year projected lifespan.[70] Though not all of the budgeting would have to be included in calculation of the accrual cost of the fleet it is not difficult to conclude that the proposed cost of the fleet is several hundred million dollars per year – if not billions. In any case, the initial acquisition can be a small percentage of the overall cost of the fleets procurement, operations, and sustainment.[71]

The Parliamentary Budget Officer (PBO) calculated the fleet total cost as being $29.3 for 65 fighters across 30 years or just short of a billion dollars per year.[72] Though it's not clear why the government budgeted for 20 years while the PBO budgeted for a 30 year life cycle the traditional extended use of service fleets suggests that the PBO was likely assessing the more realistic life of the F-35. The O&M costs go up for each additional year of service with as much

[70]Kim Richard Nossal, "Late Learners…, 174-175. It is easy to see that with sophisticated fleets such as fighters, cash budgeting can be problematic due to their large price tags.
[71]Shawn R. Jones et al., "Performance Implications of Product Life Cycle Extension…, 189.
[72]Kim Richard Nossal, "Late Learners…, 175.

as 70% of the overall cost coming after the platform is operational.[73] So, when the Auditor General extended this life cycle planning assumption out to 36 years[74] the increased O&M costs were reflected in his planning assumptions and final numbers. These increased costs reflect the fact that there are significant to planning for the use of a platform for in excess of 30 years and to assume that it will be relevant or have any military advantage. It is therefore of paramount importance that life cycles be fully defined. Only then will we be able to understand the impact of fleet cost and the cost of extending the fleet's life.

In general Canada has accounted for procurements using cash based accounting. There are strengths and weaknesses to both cash based and accrual accounting.

Cash Funding

Cash based accounting is simple to understand, define and brief in reporting, and it allows a given government to ensure that the public understands decisions and related policy. Revenue is recorded when cash is received and expenses are deducted when they are paid for.[75]

Though cash is simple in nature when a government is procuring defence fleets such as frigates, tanks, or other major weapon systems the cost within the year of procurement can be enormous. It is also difficult to have a consistent long term focus – across multiple decades – while budgeting from year to year as opposed to across the lifespan of a relevant fleet. Finally, the cost of a fleet can incorporate much more than just the capital purchase related to procurement.[76] These factors (enormous initial costs, inconsistent focus, and a range of diverse related costs) can result in cash based budgeting favouring a tendency toward poor

[73] Shawn R. Jones et al., "Performance Implications of Product Life Cycle Extension…, 189.

[74] Kim Richard Nossal, "Late Learners…, 178.

[75] Ross Fetterly, et al., *Accrual Accounting and Budgeting in Defence…*, 18. It is important to note that annual budgets are executed using cash funding – regardless of accrued fleet procurement. Parliament approves money on a cash basis to include accrued financing of a fleet within any given year.

[76] As seen with the F-35.

replace/extend decisions due to conflicts between short term budget needs and the requirement for a long term perspective.[77]

Maintenance, operating, training, ammunition (if relevant), interoperability upgrades of communications suites (if relevant), parts, and storage/housing/infrastructure/basing can all have impacts on the overall cost throughout the life of the fleet. As seen with the F-35, what constitutes a cost related to a given procurement can cause confusion and can result in a significant amount of debate. It is therefore vitally important that policy dictate what constitutes a fleet associated cost. Once cost parameters are defined, CoA comparison will be able to determine which CoA in the replace/extend decision is most cost effective.

Accrual Funding

Unlike cash based accounting in accrual accounting expenses are deducted when they are incurred – regardless of what fiscal period that may be in. Income and expenses are recorded when they occur.[78] With accrual accounting, the use of capital assets is amortized throughout the period they are designed to be used in. This amortization spreads the cost of the procurement throughout the life span of the fleet. For example, in 2006 when the fleet of (then) four C-17 were purchased the Department of National Defence (DND) was provided with $1.8B in cash from 2006 to 2011 for the actual purchase from Boeing. But, the budget from 2006 to 2011 included $149M per year in amortized expenses as part of the annual budget.[79] There are several benefits to this approach, to include: elimination of year-to-year volatility,[80] stronger allocation of resources, improved accountability, greater transparency, and a more comprehensive

[77]Mercury Associates, *Fleet Replacement Plan for the City of Prince George…*, 20.
[78]Ross Fetterly, et al., *Accrual Accounting and Budgeting in Defence…*, 19.
[79]Binyamin Solomon, and Craig Stone. "Accrual Budgeting and Defence Funding: Theory and Simulations." *Defence and Peace Economics* 24, no. 3 (2013): 212.
[80]Mercury Associates, *Fleet Replacement Plan for the City of Prince George…*, 22.

understanding of the impact of expenditures.[81] As stated earlier, the CAF has not yet had the opportunity to address a fleet which was procured using accrual funding having reached the end of its designed life. Accrual funding can potentially be applied to life extension in ways which will impact the culture of procurement in order to prioritize military advantage and design fleet life so that capability gaps will be avoided. If done correctly, there is potential for life design to pay dividends across multiple criteria defined below, and to address the ebb and flow of procurement ultimately resulting in the retention of civilian skill sets.[82]

DEFINING THE SOLUTION SPACE

Related Criteria

In order to facilitate future replace/extend decision cycles, it is important to define a common and consistent approach to addressing the problem set. To be able to consistently compare the various CoA available, we must first define the criteria by which the CoA will be compared. When comparing the three CoA in question – replacing the fleet, planned extension of the life of a fleet or unplanned extension (defined below) – the CoA should be graded across the five proposed criteria of cost effectiveness, timeliness, innovation – or the innovative application of mature yet modern S&T – regional advantage, and military advantage (encompassing not only capability but also availability). These criteria should be applied to the current approach to capital purchase through accrual financing (vice cash) and a system which flattens the current ebb and flow wave of procurement cycles through phased fleet replacement. These five criteria must be related to a definition of the capability which is required or a need

[81] Binyamin Solomon, et al., "Accrual Budgeting and Defence Funding:…, 211. See also: Ross Fetterly, et al., *Accrual Accounting and Budgeting in Defence…*, 24.

[82] Ultimately the desired goal is to maintain a steady rate of fleet building in order to retain capability through the consistent employment of skilled personnel and infrastructure. This pertains to multiple facets of building to include definition of the concept/need, research and innovation, development and design, manufacture, in-service assessment, and so forth.

which will provide a given desired effect. This need definition should realistically reflect factors from all five criteria which are defined as follows.

Cost Effectiveness

This criterion entails a detailed analysis of all project associated costs. The cost effectiveness criterion requires the conduct of a Cost Effectiveness Evaluation (CEA) which calculates the cost effectiveness of distinct policies (or, in this case CoAs) to ensure that the most efficient option is chosen.[83] The benefit portion of the Cost Benefit Analysis (CBA) reflects impacts on stakeholders, industry, employment, and government[84] and is incorporated into the CoA comparison under the follow on criteria (timeliness, innovation, regional and military advantage). Total projected costs should encompass all material costs across the entire projected life to include but not limited to: procurement, parts, tooling, requirements for space (depot) related to storage of the fleet (where applicable), planned mid-life betterment, and may include labour if there is a projected increase in cost or requirements specific to the fleet. If there are any projected risks related to the procurement which require mitigation, avoidance, or elimination derived from expenditure of funds then these costs should be included in the comparison formula.[85] This risk portion should include an assessment related to high cost risk reflecting uncertainty and a projected minimum and maximum investment required to sufficiently address the risk. With CoA 1 (replacement of the fleet) when these factors are compiled the total cost of the fleet can be calculated in order to compare the resulting cost with that of CoA 2 (planned

[83]Treasury Board, BT59-5/2007, *Canadian Cost Benefit Analysis Guide: Regulatory Proposals* (Ottawa: Treasury Board of Canada Secretariat, 2007), 29.

[84]*Ibid.*, 29-33.

[85]Australian Department of Defence, *Defence Capability Development Manual 2006* (Canberra: Director, Capability Operations and Plans, 2006), 30.

extension of fleet life). The CoA which meets the defined requirement with the lowest cost is the most cost effective CoA.[86]

This process must have a policy which defines how fleet cost is calculated and what factors will be included in the final calculation. For instance, to avoid the confusion and debate surrounding the F-35 procurement the Ministry of National Defence (MND) should define what is considered to be a factor in calculating procurement cost[87]. This will allow a fulsome calculation of annualization of net costs and allow for a true CoA comparison of the cost criterion. With the F-35, the key differences between varying costings were the inclusion or exclusion of O&M, personnel, facilities, basing demands and so forth. The more inclusive a costing formula is the more realistic a comparison will be. The suggested baseline list of cost factors in Table 5.1 (on page 42) that CoAs could commonly be compared using is a minimum required start state for understanding the cost of procurement.

Once the total cost has been calculated and the projected life cycle defined through consideration of the defined need, the cost of the fleet should be accrued across the entirety of the fleet's life (or as much of it as reasonable and necessary) including all of the relevant factors outlined below in Table 5.1. This should include all projected costs up to a designed divestment to occur at the optimum moment when life extension would become more costly than fleet replacement (as calculated across the five criteria) or when annual average costs are at their lowest. Once total cost of fleet replacement or life extension has been calculated and the dollar investment accrued throughout the entirety of either option, the most important metric related to cost effectiveness is whether or not the CoA in question meets budget constraints.

86 Christopher A. Mouton, David T. Orletsky, Michael Kennedy, and Fred Timson, *Reducing Long-Term Costs While Preserving a Robust Strategic Airlift Fleet: Options for the Current Fleet and Next-Generation Aircraft* (Santa Monica: Rand Corporation, 2012), 4.

87 Currently, this definition would need to be devised in conjunction with Public Works, Industry Canada, as well as Innovation, Science and Economic Development Canada.

Minimizing cost, however, is not the sole goal of the MND. If expenditure minimization were the sole goal then there would be no relevant consideration of fleet availability, needs, or requirements.[88] As such, the goal is to define a need, determine a requirement which provides a capability to meet that need, and then minimize the average cost per year of that capability by identifying the optimum time for fleet retirement and replacing the fleet at that time.[89] According to this criterion, if the minimum cost per year is realized through CoA 1, then CoA 1 is the best CoA and the fleet should be replaced. If CoA 2 has the minimum cost then the fleet should have a planned life extension (to include CoA 2's cost factors in Table 5.1). Impacts of the remaining criteria will need to be weighed and scored based on the fleet in question and other prevailing conditions of the day.

Timeliness

Schedule constraints must be identified in order to ensure that fleet procurement is completed in a timely manner. Timeliness will have a direct impact on the other criteria – particularly cost effectiveness and military advantage. If the fleet procurement is not initiated at a time which facilitates the replacement of the fleet then there will be a capability gap which must be mitigated, eliminated, avoided or accepted. The later the decision to replace or extend is made, the more likely it becomes that the fleet's life cycle will be extended (due to the time required to procure a replacement fleet) and that military advantage will be degraded. As seen with the CP-140 and the A-10 above, this degradation not only impacts military advantage through reduced availability but also impacts cost through increased maintenance requirements and increased need for depot investment to address demands for sustainment.

[88] In fact, there would be no fleet.

[89] Edward G. Keating, et al. *Aging Aircraft Repair-Replacement Decisions…*, 5.

There is also a need for a disciplined approach to timeliness which considers the law of diminishing returns in order to minimize the price of changing design aspects at an inappropriate time. Regarding UK fleet procurement problems a 2005 RAND report included the fact that "Changes in specifications and requirements accounted for 46 percent of schedule slippages.[90]" These changes can be minimized through the identification of an appropriate phase cycle for each given fleet. Emerging technologies can be incorporated into the next phase of the cycle when the relevant and advantageous technology has had an opportunity to mature, and the program is able to apply it to the appropriate phase of production without incurring costs by altering the present planning phase. This is only applicable to fleets where percentages of the given fleet can be phased into service in a given year (such as 10% of the fleet entering into service each year across a ten year phasing).

Innovation

The innovation criterion is also intimately tied to each of the other criteria. If a given CoA includes the innovative application of S&T or otherwise provides a capability which increases military advantage or decreases cost then the CoA is scored appropriately. As per Table 5.1, this could include such factors as improved accuracy, C4 ISR capability, combined or joint interoperability, and so forth.[91]

Means of improving cost effectiveness through innovation could include families of platforms built using common components such as engines or tires which is known as

---

[90]Stuart Young and Jonathan Davies, "United Kingdom Warship Procurement Strategies: Accident or Design?" in *National Approaches to Shipbuilding and Ship Procurement*, ed. Douglas L. Bland (Kingston: Queen's University, 2010), 9.

[91]National Defence and the Canadian Armed Forces, "Defence Acquisition Guide," last accessed 14 April 2017, http://www.forces.gc.ca/en/business-defence-acquisition-guide-2016/index.page. The Defence Acquisition Guide does emphasize the importance of ensuring that old and new systems can work together and that equipment remains compatible with that of other nations. What is being suggested here is that these factors be considered as a key component of the innovation criteria when determining whether or not a fleet should be replaced or have its life extended.

commonality. Commonality can realize savings in parts, R&D (through spreading research costs across multiple programs) and training.[92] For instance, although their turrets are logistically distinct, the Coyote and the LAV III family all have the same gunnery components and turret design making gunnery training common - though they are otherwise distinct in engines, tires, and many other components.[93] A civilian example is that of the A-320, A-330, and A-340 airliners sharing common cockpit controls and displays which saves airlines 20 to 25% in costs related to Airbus pilot training.[94]

Another example is hybridization. Hybrids combine the characteristics or capabilities of things which are normally separate or distinct. The intent is to provide an item which reduces costs by satisfying needs which were previously addressed by two or more items. The classic example of hybridization is the Swiss Army Knife which satisfies the requirement of a knife, a toothpick, scissors, and so forth in one convenient package. Intuition says that hybridization will provide lower costs. But the final impact of the hybridization must be calculated. For instance, if the fiscal impact of the capability being added to a platform is relatively inexpensive then there may be value in adding it. If the sum of the hybridized parts is more expensive than the non-hybrids otherwise providing those capabilities then the effort of hybridizing is not worth considering. This cost applies to military advantage as well. If the capability of the hybridized parts is less advantageous than the non-hybridized then the capabilities should not be housed in

[92]Thomas Held, Bruce Newsome, and Mathew W. Lewis, *Commonality in Military Equipment: A Framework to Improve Acquisition Decisions* (Santa Monica: Rand Corporation, 2008), 30-32.

[93]As of 2022 all Remote Weapon Systems on the LAV III will also be common. See: National Defence and the Canadian Armed Forces, "Light Armoured Vehicle (LAV) III Upgrade Part 2," last accessed 14 April 2017, http://www.forces.gc.ca/en/business-defence-acquisition-guide-2016/land-systems-150.page.

[94]Hugh McManus, A. Haggerty, and E. Murman, "Lean Engineering: Doing the Right Thing Right," *The Aeronautical Journal* 111, no. 1116 (February 2007), 110.

the same fleet.[95] For example, camouflage designed to work in both temperate and arid climates is likely to be effective in neither climate.

Opportunities to increase military advantage or save on cost through the innovative application of S&T, commonality, or hybridization should be considered as factors when comparing the three CoA related to the life of CAF fleets. If a given CoA encompasses opportunities to realize savings, efficiencies or advantages through innovation then it should be weighed in accordance with those strengths. However, it is important to consider the impact on military advantage. The CAF must be careful not to weigh innovation and hybridization high at the expense of military advantage or the resulting fleet may achieve cost savings at the expense of effective capability.

Regional Advantage

If a given CoA includes greater incorporation of a product or technology provided from within Canada which will assist with regional development, job retention, or industrial competition, then that CoA should be scored higher than the others in this criterion. The intent behind this comparison criterion is not just to provide related work within Canada but to maintain consistent Canadian job retention, financial security, and fleet production capability in support of the nation's defence. As it stands now Canada does correctly prioritize regional advantage and should continue to do so. But there remains room for improvement. In 2007, 46% of Canadian defence services and sales derived from within Canada. The remaining 54% came from sources outside of Canada (US, Europe, Asia, etc.).[96] By developing a consistent approach to maintaining Canadian defence production capabilities and flattening the ebb and flow of construction there could be long term improvement to these numbers.

[95] Thomas Held, et al., *Commonality in Military Equipment…,* 54.

[96] Steven Tzeferakos, "The Canadian Defence Sector," in *2010 Canadian Defence Industry at a Crossroads*, ed. Craig Stone (Kingston: Queen's University, 2010), 4.

As a relatively small nation, these types of jobs are particularly important due to their relevance to the economy and to education. Small nation governments often find it difficult to find the correct balance between security and other socioeconomic considerations[97]. However, fleet production and procurement jobs are sophisticated in nature requiring a great degree of education and training. They are intimately connected to the leading edge technology needed to develop and manufacture advanced weapons systems and other defence capabilities. These high tech jobs produce high-value employment which governments should foster due to their second and third order effects on the economy benefiting a wide range of socioeconomic considerations.[98]

To ensure long term retention of jobs and economic impact, fleet construction and procurement must be done in a manner which levels the current ebb and flow or else capability and skill retention will eventually degrade. As it stands now, shipbuilding in particular is not stable due to the irregularity of naval shipbuilding contracts. As a result the industry has indicated in the recent past that it is unwilling or unable to invest in modernization of shipyards or to increase the skills of their labour force.[99] In the short term this has been addressed with the upcoming construction of the Joint Support Ship (JSS),[100] Arctic Offshore Patrol Ships (AOPS)[101], and the CSC.[102] But, long term policy and fleet production/replacement/extension

[97]Stefan Markowski and Robert Wylie, "Australian Naval Shipbuilding Strategy 2009…, 95.

[98]Ross Fetterly. "Shaping Future Procurement Strategies…, 48.

[99]*Ibid.*, 51.

[100]National Defence and the Canadian Armed Forces, "Joint Support Ship," last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/joint-support-ship.page. The JSS has a budget of $6.8 billion for two ships which will see full operational capability in 2022 with a projected life of 30 years. These projects represent a significant flow or wave – the key is to find a way to balance this wave so that it is not followed by an industry damaging ebb.

[101]National Defence and the Canadian Armed Forces, "Arctic Offshore Patrol Ships," last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/arctic-offshore-patrol-ships.page. The AOPS has a budget of $9 billion for 6 ships which will see full operational capability in 2023 with a projected 25 year life.

[102]National Defence and the Canadian Armed Forces, "Canadian Surface Combatant," last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/canadian-surface-combatant.page. The CSC has a budget of $26.2 billion for up to 15 ships which will see full operational capability in the mid-2040s.

guidelines which will address the boom bust cycles must be designed to ensure that the correct CoA is consistently selected in future decades.

The current National Shipbuilding Strategy purports to create or maintain 5500 jobs and to contribute $4.4 billion dollars per year to Canada's gross domestic product from 2012 to 2022.[103] This will be done through rebuilding shipyards and constructing a series of combat and non-combat vessels for the Royal Canadian Navy and the Coast Guard as well as a program of vessel repair, refit and maintenance. All of this is done while emphasizing the importance of eliminating cycles of boom and bust by making investments in the marine industry in order to retain capability. But, the strategy reads very much like a boom having followed a 1990 to 2012 bust. The proposed regional advantage criteria must consider means of flattening the wave of construction in order to ensure consistent development and employment. When determined appropriate – through the conduct of a thorough replace/extend CoA comparison – fleets should be phased in and out so that regional advantage can be maintained. This would be one means of meeting Canada's defined objective of capitalizing on major purchases to generate the maximum possible economic benefit to Canadian industry and the economy.[104] Phasing fleet production in order to deliver percentages of a fleet at predetermined intervals would ensure that contracts bring long-term significant economic activity to Canada.

The irregular ebb and flow of fleet procurement makes it difficult for the defence industry to retain talented workers within the competitive high skill markets of design and engineering. There are currently too few incentives to maintain a high salary pay roll of skilled professionals when not in a period of construction boom – as we saw from 1990 to 2012, and could potentially

[103]Public Services and Procurement Canada, "National Shipbuilding Strategy," last accessed 17 February 2017, http://www.tpsgc-pwgsc.gc.ca/app-acq/amd-dp/mer-sea/sncn-nss/index-eng.html.

[104]Gregory H. Van Bavel, "Balanced Procurement, Military Advantage, and the Canadian Defence Industrial Base" in *2010 Canadian Defence Industry at a Crossroads*, ed. Craig Stone (Kingston: Queen's University, 2010), 42.

see after delivery of the CSC. This lack of incentive carries on through significant orders of effect within regional economies. Retention of skilled professionals and regional benefits can be realized through the flattening of the procurement wave by a disciplined approach to fleet replacement. This approach should include regular replacement of portions of a given fleet (vice irregular replacement of the whole), and through avoiding unplanned life extension in order to maximize military and regional advantage as well as maximizing the application of innovation and S&T - making regional advantage a decisive criterion for the judgement of procurement processes.

Some fleets we will not be able to build entirely in Canada. Modern high tech fleets – such as the F-35 – will require input and production from multiple nations and will need to have a separate approach as their very nature does not lend itself to phased replacement. With these types of fleets it will not always be possible to make them in Canada or to maximize regional benefit. During the 1977-1982 purchase of the current F-18 fleet for instance, budgetary constraints forced an "off the shelf" purchase from McDonnell-Douglas. "The option of building the aircraft in Canada under license to a foreign company was deemed too expensive.[105]" Conversely, military advantage can be prioritized and cost efficiencies realized through off the shelf purchases (where appropriate) of complex weapon systems which would likely be more expensive and less effective if made in Canada.[106]

Military Advantage

Military advantage facilitates the direct accomplishment of the mission while minimizing risk. In today's risk adverse socio-political environment minimizing casualties as much as possible is a key consideration when comparing CoAs. In conjunction with other strategic

[105] Kim Richard Nossal, "Late Learners…, 171.

[106] Stefan Markowski and Robert Wylie, "Australian Naval Shipbuilding Strategy 2009" in *National Approaches to Shipbuilding and Ship Procurement*, edited by Douglas L. Bland (Kingston: Queen's University, 2010), 95.

levers, if a given nation has military advantage then that nation will have a greater chance of accomplishing its mission.[107] Military advantage provides the CAF with the ability to weaken, destroy, or otherwise have a desired effect on the enemy at a place and time of CAF choosing. Without a concerted application of an advantage related success criterion Canada will be forced to abdicate "from involvement in multinational operations in which Canada would be expected to play a meaningful role, or it will cause unnecessary risk to aircrews attempting to accomplish the goals asked of them by their country.[108]" This includes a requirement to develop and maintain capabilities which are competitive in the FSE, compatible with those of our partners, and robust enough to fight, survive and win in today's demanding battle space. Military advantage allows Canada to deter conflict or to succeed in battle when deterrence fails. These are key considerations in today's risk adverse political environment. As per Table 5.1 below, factors related to military advantage include C4ISR capability and compatibility with other nations, mobility (both tactical and strategic), lethality, and protection. When determining whether or not to replace a fleet, the fleet's ability to provide advantage when compared to comparable foreign fleets should be a key decisive criterion for the judgement of procurement processes.

Each of these five comparison criteria, proposed minimum factors related to them, and metrics for defining their success are outlined within Table 5.1, below. Each given fleet will require an examination of the related criteria and metrics in order to ensure that the budgetary constraints specific to cost effectiveness are weighted in a manner which reflects fiscal realities in the year of CoA comparison. Most importantly, there is a requirement for policy definition of

[107]Gregory H. Van Bavel, "Balanced Procurement…, 12.
[108]William Weston C. "CF-18 Systems Life Extension…, 15. This would be due to Canadian fleets not meeting the capability standards of allied nations – such as: profile (stealth capability), communication suite compatibility, rapid deployability, and so forth.

what expenses will be included in the cost estimate (which would constitute the criteria definition) in order to facilitate a fair and realistic comparison of the CoAs.

Metrics related to the timeliness criterion are tied to the predicted time required to either procure a replacement fleet (as graphically depicted in Figure 6.1, below) or to prepare the sustainment support required to conduct a planned life extension. If these preparations are not sufficiently executed then there will be a cost to military advantage in lost capability, lost availability, or both. Innovation metrics will likely be related to increased capability or to reduced cost. Regional advantage will be tied to national or provincial economic dividends. And, successful military advantage will be defined by platform specific capabilities such as firepower, mobility, and protection. Further examples are provided within Table 5.1.

CoA Comparison Criteria	**Criteria Definition**	**Related Factors to be Considered in Weighing Criteria**	**Metrics Defining Success of Criteria Consideration**
Cost Effectiveness	Total defined projected costs across the entire planned life of the fleet (using commonly defined parameters)	-Initial Procurement -Parts -Tooling -Space (buildings for storage of fleet, parts, maintenance facilities, related offices and other infrastructure) -Planned betterment -Risk -Divestment	-Direct financial procurement cost comparison between CoA 1 and CoA 2 -Cost per operational hour or km -Meeting of budget constraints or -Budget compliance
Timeliness	-Decision is made at an optimum time which accounts for the fact that either CoA must be appropriately funded -If the CoA comparison is not conducted in a timely manner then CoA selection may be forced into a CoA 3	-Flexibility -Time remaining until projected optimum fleet replacement date -Time required to procure replacement -Time required to adequately prepare for life extension	-Timely CoA selection with related measurements CoA 1: new procurement timeline and cost CoA 2: Depot preparation timeline and fiscal cost or cost to military advantage measured in capability and availability

	due to insufficient time remaining to select CoA 1 or 2		
Innovation	Incorporation of technological progress to include new methods, ideas, devices and products in novel and relevant ways	-Technological relevance -Application of mature S&T -Commonality -Technologically based survivability, range, lethality, mobility, etc.	-Rapid transmission of information related to C4ISR across the operational functions of Command, Sense, Act, and Shield -Facilitation of a Common Operating Picture -Increased military advantage -Decreased cost
Regional Advantage	Project and procurement regulation in support of national economic interests	-Location of construction / source -Job retention -Skill retention	-National procurement vice off the shelf international or Canadian license production
Military Advantage	Provision of the ability to weaken, destroy, or otherwise have a desired effect on the enemy at a place and time of CAF choosing	-C4ISR capability and compatibility -Mobility -Firepower -Protection -CBRN protection -Profile	-Protection of platform and personnel -Lethality -Range -Maneuverability defined in terms of both tactical manoeuvre and strategic/operational mobility intra theatre -Trusted International Partner compatibility -Mission Capable Rates

Table 5.1 – CoA Comparison Criteria

CoA Comparison

At the decision point within Figure 6.1, prior to a fleet reaching the end of its designed life there are three potential CoA[109], each with their own strengths and weaknesses.[110] These CoA are: replace the fleet, conduct a planned fleet life extension, or conduct an unplanned fleet

[109]Realistically there are significantly more than just three CoA. However, for the purposes of addressing means of flattening the current wave of procurement costs three CoA provide sufficient room for discussion.

[110]In addition to individual CoA tables below, a table compiling the strengths and weaknesses related to the three CoA can be found in Annex A.

life extension. These CoA, along with their distinct strengths and weaknesses, are defined below. Strengths and weaknesses are addressed using the five proposed CoA comparison criteria of cost effectiveness, timeliness, innovation, regional advantage, and military advantage. In future examination, each of these CoA would have to be suitable (in accordance with the definition of need and capability), feasible (within budget), acceptable (conform to Canadian societal norms), compliant (conform to policy, regulations, legislation and guidelines), exclusive (fundamentally different from one another), and complete (clearly identify and meet all requirements).[111]

CoA 1 - Replace the Fleet

This CoA entails complete or phased replacement of the fleet with a new platform. There are several factors which must be taken into account to facilitate this CoA – to include (but not limited to): definition of the capability or effect required[112] and a determination of the number of platforms in the new fleet needed to achieve that defined capability. As per Figure 6.1, in order for this CoA to be successful without a capability gap the life of the fleet must be designed with an appropriate decision point which is designated early enough to allow for today's extended procurement timelines. As per Table 5.1's Innovation criterion, and Table 5.2 below, if the decision point is not identified and actioned early enough to allow for procurement or to position sustainment requirements then decision makers may be forced to either address a gap in capability or choose an alternate CoA. Strengths and weaknesses related to CoA 1 are summarized in Table 5.2, below.

As seen with the A-10 and the CP-140 examples above, CoA 1 is often avoided due to its high initial cost but can be cheaper in the long run than extending a fleet's life due to increasing

[111] Department of National Defence, B-GJ-005-500/FP-000, *The Canadian Forces Operational Planning Process (OPP)* (Ottawa: Chief of Force Development, 2008), 3-4.
[112] Australian Department of Defence, Defence *Capability Development Manual…,* 4.

O&M and betterment expenses. That said there are advantages to CoA 1 across several comparison criteria. CoA 1 allows for the greatest application of S&T which can provide significant military advantage and facilitates Canada's retention of highly trained and educated workers. Military advantage can also be achieved through a reduced requirement for maintenance and other sustainment needs, related reduced downtime, and increased availability; All of which can reduce cost (as seen with the A-10) and avoid capability gaps (as seen with the AOR).

Course of Action	Strengths	Weaknesses
Replacement	**Cost Effectiveness** -Decreased maintenance and related downtime -Allows for fleet retirement at optimal retirement age which sees lowest average cost of fleet per year **Innovation** -Maximum allowance for innovative application of S&T **Regional Advantage** -Improved job retention -Maximum investment in regional economy **Military Advantage** -Increased availability -Increased reliability -Potential for increased capability (design dependant) -Improved TIP compatibility	**Cost Effectiveness** -Increased initial cost (may be mitigated through accrual budgeting) **Timeliness** -Decision to replace fleet must account for the significant amount of time which fleet procurement currently takes – if decision is not made at the appropriate point there may be a capability gap or a force toward CoA 2 or 3

Table 5.2 – CoA 1 Replace the Fleet

CoA 2 - Planned Life Extension

This CoA entails extending the life of the current fleet as opposed to procuring a new platform. There are several factors which must be taken into account to facilitate this CoA – to include (but not limited to): an examination of the capability or effect which the fleet originally fulfilled and a determination of whether or not the capability requirement has changed or if the existing fleet and the number of platforms within it still achieve that defined capability. As per Figure 6.1, in order for this CoA to be successful without a capability gap the life of the fleet must be designed with an appropriate decision point which is designated early enough to allow for a likely increase in sustainment demands. An assessment must be made regarding the cost of increased requirements for parts, maintenance, and related depot capacity as well as increasing strain on the current maintenance systems. A further assessment is required to ascertain what the impact of this increased maintenance will be in terms of not only fiscal cost but also cost within the military advantage criteria (impacting both capability and availability). As per Table 5.3, if the decision point is not identified and actioned early enough then decision makers may be forced to either address a gap in capability or choose CoA 3.

As seen with the A-10 and CP-140 examples above, the requirements for increased sustainment found in CoA 2 can be neglected. Or, the fact that costs related to CoA 2 can be greater than costs related to CoA 1 is sometimes ignored. That said if increased sustainment demands are correctly addressed by positioning parts and maintenance capabilities, and providing related storage needs, there can be advantages to CoA 2 across several comparison criteria. For example, CoA 2 allows for some application of S&T if there is planned betterment. As seen in Figure 1.3, there can be some short term saving across a limited number of years until the average cost per year begins to climb following the optimum replacement age. Other strengths and weaknesses are summarized in Table 5.3.

Course of Action	**Strengths**	**Weaknesses**
Planned Life Extension	**Cost Effectiveness** -Avoids fiscal shock of new fleet purchase **Innovation**	**Cost Effectiveness** -Can be long term Increased overall cost (may be mitigated through accrual budgeting of

	-Allows for innovative application of S&T if there is a betterment or life cycle extension plan **Regional Advantage** -Can allow for job retention (through betterment) -Can allow for investment in regional economy (through betterment) as well as the purchase and placement of spare parts and other sustainment facilitators. **Military Advantage** -Some improvement to availability over CoA 3 (with life cycle investment) -Improved reliability over CoA 3 (if sustainment needs met) -Potential for increased capability (extension design dependant)	life extension) -Likely increased sustainment demands must be met or cost effectiveness and availability portion of military advantage will be severely degraded **Timeliness** -Decision to conduct a planned life extension must account for the time required to plan for and facilitate sustainment needs to include: stockpiling of parts, increased demand for depot capacity, and other maintenance needs – if decision is not made at the appropriate point there may be a capability gap which will force CoA 3 **Military Advantage** -Will not account for as many potential improvements to capability and availability as CoA 1

Table 5.3 – CoA 2 Planned Life Extension

CoA 3 - Unplanned Life Extension

This CoA also entails extending the life of the fleet as opposed to procuring a new platform. If done correctly this CoA should still see an examination of the capability or effect which the fleet originally fulfilled and a determination of whether or not the capability requirement has changed; or, if the existing fleet and the number of platforms within it still achieve that defined capability – keeping in mind that the number of available platforms will reduce as the fleet ages (as with the CF-18). This CoA is distinct from CoA 2 in that there is no associated betterment or allowance for increased sustainment demands. There should still be an assessment regarding the cost of increased requirements for parts, maintenance, and related depot capacity as well as strain on current maintenance systems. There also remains a demand for an assessment to ascertain what the impact of this increased maintenance will be in terms of cost within the military advantage criteria (impacting both capability and availability).[113] These assessments are required to understand the likely impact of choosing CoA 3 which could include increased cost, reduced capability and availability as well as impacts on regional advantage due to inconsistent or irregular use of regional industry, trained personnel, and facilities. These impacts are summarized in Table 5.4.

Course of Action	**Strengths**	**Weaknesses**
Unplanned Life Extension	**Cost Effectiveness** -Reduced initial cost **Timeliness** -No requirement for timely consideration **Regional Advantage** -Eventual increased need for maintenance could see unprogrammed investment	**Cost Effectiveness** -Long term overall cost increased -Increased maintenance and other O&M **Innovation** -No application of S&T **Regional Advantage** -No investment in jobs or regional economy **Military Advantage** -Outdated capability -Reduced availability

Table 5.4 – CoA 3 Unplanned Life Extension

Finally, upon completion of the various assessments required, a CoA comparison must be completed between CoA 1, CoA 2, and CoA 3 – encompassing all comparison criteria – in order to determine which is the most desirable. Realistically cost and budget constraints will have the greatest weight but as seen with the CP-140 that does not necessarily mean that CoA 2 or 3 will be cheapest.

[113] If this CoA is chosen then there is likely an accepted reduction in capability and availability.

DESIGINING A SOLUTION

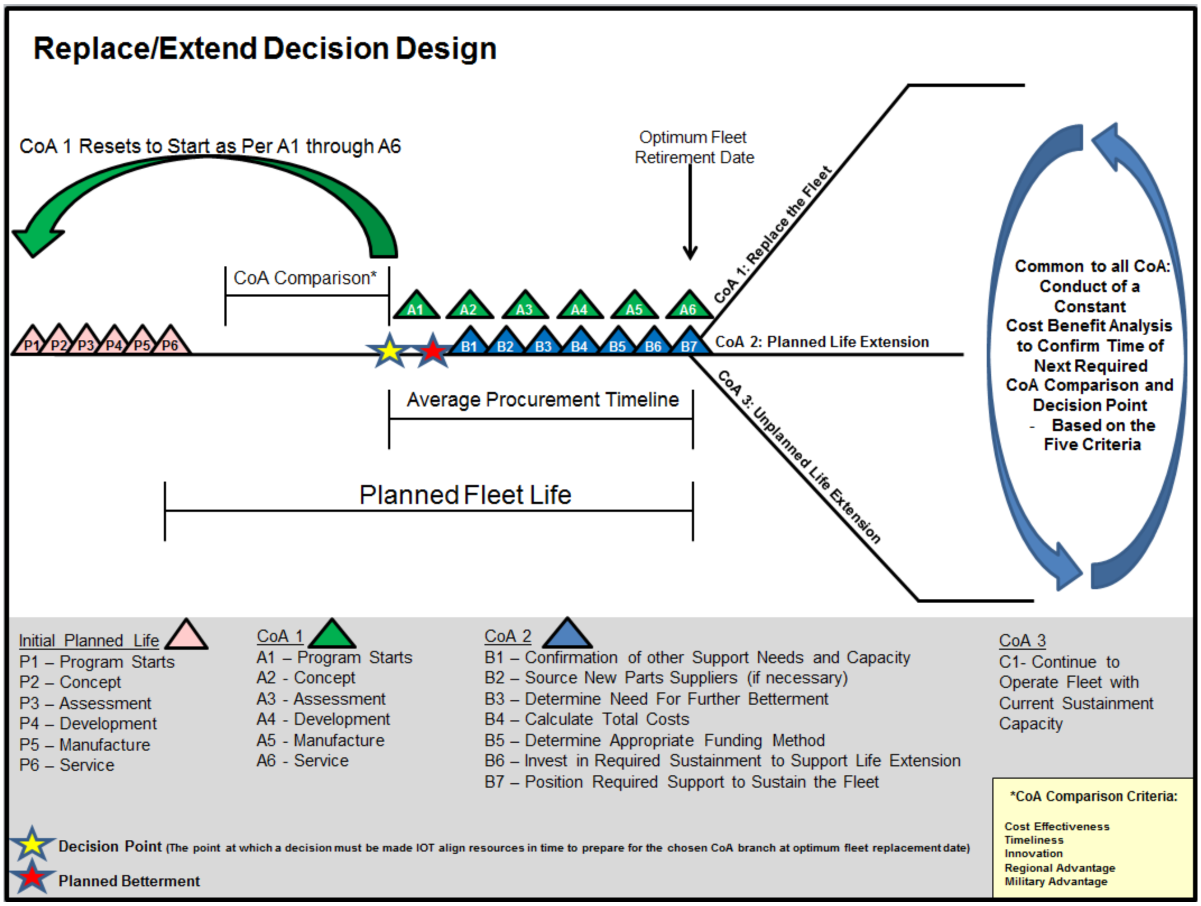

Figure 6.1: Replace/Extend Decision Design

Figure 6.1 graphically illustrates the proposed replace/extend CoA decision process. This process begins with an analysis of need to be fulfilled by the fleet in question which initiates the program at decisive point P1. This initiation is followed by the normal procurement process of concept definition, assessment, project development, manufacture, and fleet service.[114] This design proposes that the fleet's life be drafted in its entirety by a point as early in the program as possible. This draft should include every possible aspect from manufacture to optimum retirement date and decommissioning. Utilizing programs such as the Defence Resource

[114]This list is rudimentary in nature and has several implied decisive points key to fielding a new fleet.

Management Information System (DRMIS)[115] and historical data on existing and recent fleets, the CAF should be able to estimate what the optimum retirement age of the fleet will be such that the lowest possible average cost of yearly fleet existence is achieved. From the fleet's final operational capability declaration to the optimum retirement age is known as the planned fleet life. Costs associated with this fleet life must be defined in accordance with a policy statement outlining what constitutes fleet related cost which should include everything from expenses related to program initiation to planned betterment mid-life and decommissioning. As seen with the F-35 on page 28, this policy definition is required to provide a common understanding of what factors will be included in calculating the cost of a fleet and to facilitate the replace/extend decision process.

Once the optimum retirement date has been identified and related costs calculated, the procurement should be accrued across as much of the designed life as feasible or necessary to ensure allocation and transparency. It is important to account for betterment and midlife improvements to allow for modernization and to ensure military advantage. Some of these costs could be incorporated into the accrual purchase, but there must remain flexibility in financing in order to allow for agile improvements in response to unforeseen needs. An analysis of historical costs related to mid-life upgrades in similar fleets could be useful in budgeting for necessary upgrades in response to technological and operational changes which will have occurred since the fleet's initial acquisition.[116]

[115]National Defence and the Canadian Armed Forces, "Defence Resource Management Information System In-Service Support," last accessed 3 May 2017, http://www.forces.gc.ca/en/business-defence-acquisition-guide-2015/joint-and-other-systems-899.page. DRMIS is used by the CAF to support operations and training by tracking materiel and financial systems as well as by reporting on performance. With a phased initiation which began in 2010, DRMIS is relatively new. It has great potential for assisting with the replace/extend decision process by providing costs associated with each of the related CoA, by summarizing the state of the fleet, and by providing other information useful to assessing the likely impacts (in terms of cost and availability) of each CoA across the 5 comparison criteria.

[116]William Weston C. "CF-18 Systems Life Extension…, 13.

Once the fleet's life has been drafted and the optimum retirement age identified (with the lowest possible average yearly costs) then a decision point must be identified by averaging the length of procurement timelines and drawing that length to the left of the optimum retirement date. For instance, if a given type of fleet requires an average of 15 years to procure then the replace/extend decision must be made 15 years prior to the optimum retirement date. This decision point will not immediately result in a branch as per an operational design or a decision tree. Instead, the decision point here indicates the point at which a decision must be made in order to prepare and position the resources needed to execute the CoA chosen to be carried out at the current fleet's optimum retirement date. Following the decision, use of the current fleet continues beyond planned betterment until the optimum retirement date when it is either replaced, goes through a planned life extension, or an unplanned life extension. If the decision point is not designated early enough to allow for each CoA's required preparations (as illustrated by decisive points A1 through A6 and B1 through B7) then there will be a capability gap or reduced availability and potentially increased cost.

Once the time of the decision point has been designated the CoA comparison must be prepared prior to the decision point so that all information pertaining to the 3 CoA and 5 CoA comparison criteria can be compiled, prepared and confirmed. This process will likely require a significant amount of time as data will need to be mined from DRMIS and other similar materiel O&M tracking programs in use across the elements utilizing the fleet in question. This data could be both qualitative and quantitative in nature and thus may involve convening a board to ensure that the comparison is properly resourced. Fleet managers may have a separate set of CoA comparison criteria or they may add criteria such as safety and environmental impact if relevant and necessary to the fleet in question. Or, managers may weigh the proposed criteria in order to reflect factors relevant to the fleet or time of the comparison. These additions could add to the time and resources required to facilitate the decision making process.

If the decision is made to replace the current fleet then the new program must begin as soon as possible in order to ensure that the newly procured replacement fleet is fielded and ready by the optimum replacement date of the current fleet. This new program is depicted by the green decisive points A1 through A6 which are lined up to see new fleet service correspond to the current fleet's decommissioning and which occur concurrent to the current fleet's use throughout the remainder of its life.

If a planned life extension is chosen at the decision point then a separate estimate must be conducted to confirm the CoA comparison's calculation of what the requirements and costs associated with that extension will be. In this case the decision must still be made early enough to facilitate either CoA. If CoA 2 is chosen then presumably it is because the current fleet is assessed to remain capable of effectively fulfilling the defined need post optimum retirement age and that costs[117] related to increased demand on maintenance and sustainment are determined to be less than the savings potentially realized by replacing the fleet. The time between the decision point and the optimum retirement date must be used to confirm capacity available to sustain this aging fleet and to augment that sustainment capacity where necessary. This process is illustrated in Figure 6.1 by decisive points B1 through B7. If this increased demand on sustainment is not correctly defined and prepared for then there will be a capability gap or reduced availability.

There is no such thing as a free life extension. If the costs associated with increasing depot level sustainment capability are not accounted for – and sustainment capacity is not

[117]The word "cost" here refers to both financial costs specific to the cost effectiveness criterion, and to costs related to other criteria such as regional advantage or military advantage.

increased in correlation with the fleet's age – then the fleet will degrade in capability and availability as platforms await maintenance due to queuing.[118] Therefore, if a decision is not made in a timely manner and CoA 3 is the chosen course, then risks related to inevitable reduced availability and increasing costs will need to be addressed and accepted.

A significant portion of this cost is related to the incremental increase in requirement for programmed depot level maintenance (Second-Line, Third-Line or higher). Keating et al demonstrate that for the USAF C-5A fleet, Programmed Depot Maintenance (PDM) rose proportionately to the age of the fleet. For instance, when the fleet was 7 years old, it required 10000 hours of PDM per aircraft, at 15 years it required 20000, at 20 years, 35000 – and so forth. This significant increase in hours of labour captures not only intensive maintenance but also depot level overhaul related to life extension projects and encompasses increased demand on parts, as well as requirements for increased investment in parts procurement and stockpiling.[119] Further, with age we see increased demand for depot level overhaul – demonstrating that the later an overhaul happens within a fleet's service life the longer that fleet will spend in overhaul in order to update it sufficiently for relevant service. As such, if a fleet will be overhauled or have its life otherwise extended, the earlier that overhaul takes place, the less time the overhaul will take, the less the impact on depot capacity and readiness.[120]

Though this overhaul provides greater capability it clearly takes the platform offline for extended periods of time and represents a significant decrease in platform availability and therefore degradation in military advantage. Such significant increase in requirement for depot level maintenance and overhaul also requires a significant investment in overhaul capacity (maintenance space/overhead, skilled labour, etc.) in order to avoid large scale queuing and delay

[118]Edward G. Keating, et al. *Aging Aircraft Repair-Replacement Decisions…*, 39-42.
[119]*Ibid.*, 14-15.
[120]*Ibid.*, 43.

and to minimize impact on availability - which becomes very problematic if done in a boom and bust manner. Wave investment approaches do not lead to effective retention of skilled labour in the private or public sector. This lack of availability has a significant impact on military advantage. It demonstrates the importance of targeted planning for the synchronized disposal of fleets timed to occur at an optimal date in order to maximize benefits across the five criteria and occur when its replacement fleet is ready to roll out.

That said infrastructure investment requirements will factor in both CoA 1 and 2, as new fleets may have different or enhanced infrastructure, land needs or other impacts on basing. Whichever CoA is ultimately chosen, infrastructure costs related to a fleet must be factored into CoA comparison. These costs must encompass the entire life of either CoA calculated for comparison purposes. Once the most effective and efficient CoA has been chosen and related costs calculated, the procurement or extension should be accrued across as much of the designed new or extended life as feasible or necessary to ensure allocation and transparency and to flatten the wave of cost often associated with the purchase of capital fleets.

Regardless of which CoA is chosen, once the new or extended fleet is in use, there must be a re-initiation of the process to determine when the optimum retirement date of the new fleet will be. This will allow fleet managers to identify the new corresponding decision point (based on a new assessment of procurement timelines), parameters for the eventual new replace/extend CoA comparison, and so forth. This is illustrated in Figure 6.1 by the conduct of a constant cost benefit analysis to confirm the time of the next required CoA comparison and decision point based on the 5 criteria (on the right hand side of the Figure).

Potential for Strain on Flexibility

If the entire budget is tied up in accrual purchases and extensions then there will be no funds available to address short term or unforeseen needs and agility will suffer which is an unacceptable risk in the FSE. The MND must devise a system of procurement which addresses the fiscal needs and regional benefit of the Canadian public, facilitates the preservation of national integrity through the provision of military advantage, and remains relevant through the application of state of the art S&T.[121] There must be a procurement approach devised which ensures that agility, military advantage and the innovative application of emerging technologies is not hindered by tying up every annual budget through the financing of accrual based capital fleet purchases.

One means of ensuring agility is to reduce the procurement cycle time line. Throughout the 1990s, defence procurement cycles became protracted in comparison to civilian procurement with military procurement taking as much as 2.5 times longer than commercial cycles.[122] This is likely due to the fact that commercial interests lie in profit and decision making processes which value efficiency – whereas defence interests lie in regulations and bureaucracy designed to manage risk. As a result, procurement reform should seek to incentivize agility and efficiency while identifying means with which the defence industry can be leveraged to incentivize rapid and efficient means of cost savings realized through tight procurement cycles with regulated cost effective replacement of fleets. If reduced procurement timelines are not possible, then in accordance with Figure 6.1 replace/extend decisions will have to be made early enough to account for the time it takes to procure fleets.

[121]These factors are derived from the procurement success criteria of cost effectiveness, timeliness, innovation (S&T), regional advantage, and military advantage.

[122]Ross Fetterly. "Shaping Future Procurement Strategies…, 53. See also: Richard Gimblett, et al., *Vimy Paper 1: Creating an Acquisition Model That Delivers…*, 29.

CONCLUSION

Thus far the CAF has been unable to reduce procurement timelines. Fleet life design has seen inefficient extensions resulting in life cycles which are too long and more expensive than replacing the fleet. When presented with a replace/extend problem set, the GoC appears to be loath to purchase new fleets possibly because of a perception that it is more expensive than extending the life of the current fleet. This tendency can result in reduced capability due to outdated S&T and C4ISR capacity as well as reduced availability and cost effectiveness related to the increasing maintenance demands of aging fleets. By designing an informed replace/extend decision process this paper has proposed some potential approaches to reducing the scale of this problem.

Due to the complexities of the FSE, and the impact of S&T, it is in the best interest of the GoC to make timely informed decisions to regulate the process of procurement, betterment, and divestment. Where possible, to flatten the boom and bust waves of procurement, defined cycles which see a fixed portion of a given fleet brought on line at predetermined intervals should be utilized. These intervals would be determined by the nature of the fleet. Long term service fleets such as the CSC with significant life spans and related costs would have longer replacement intervals with for instance one of the fleet's 12 to 15 ships replaced every 2 years starting some time in the 2060 time frame.

For each fleet in service separate and regular cost benefit analyses must be conducted in depth in order to determine that fleet's optimal replacement strategy. This strategy will incorporate the five criteria of cost effectiveness, timeliness, innovation, regional advantage, and military advantage in order to determine the optimum time to replace the fleet. This CoA comparison would entail utilizing DRMIS and historical data to calculate the lowest average annual cost of a fleet and to determine when maintenance costs will likely become greater than the cost of replacing the fleet. Optimum fleet replacement takes place before the impact of maintenance and outdated S&T render the fleet too expensive and its capability irrelevant in the modern battle space. Wherever possible – on a fleet case by case basis – the cost of this replacement should be mitigated through the use of accrual budgeting and phased replacement with emerging technology incorporated through planned betterment.

The overall goal is to address acquisition times by making timely decisions which account for today's extended procurement timeframes. This will provide relevant and current capability while improving availability at a lower cost, all while delivering budgetary stability and improving risk management. The issues of rapid technological change combined with budgetary constraints can be addressed through a procurement cycle optimized with defined cyclical phasing financed with accrual purchase.

The most desirable endstate is the production of a capable platform or fleet for advantageous employment by the CAF which provides a sustainable, regular, and reliable economic boost to domestic industry at an acceptable cost. DND should utilize defined replace/extend CoA comparison criteria (such as cost effectiveness, timeliness, innovative application of mature yet modern S&T, regional advantage, and military advantage) to design the overall life of a given platform. That life must include an appropriately defined and financed betterment in order to ensure that the platform remains operationally viable and relevant throughout the entirety of its life. The total cost of the platform must then be calculated – from inception to optimal disposal. The disposal date is determined – using the five criteria – by calculating when it becomes cheaper to replace the platform than to better it or to extend its life cycle.[123] Impact across the five criteria must be considered when determining the total cost. Once the date for disposal has been determined, a platform to replace the capability must be designed to come on line at the optimal time. Gaps are expensive and related risks must be either accepted, financed (avoided), or mitigated. If DND chooses to extend the life of the platform (vice replace it) then that decision's support factors must be robust enough to make the extension cost effective. Otherwise, the Canadian public's limited resources will not have secured the optimum value for its money. Parts, maintenance facilities and personnel must be increased as the wear and tear on the platform will likely make significant demands on the support structures.

To minimize the current tendency toward waves of spending followed by decades of use, DND should consider replacing portions of fleets at fixed periods. This approach would not only flatten the spending wave but would allow for the application of recent and relevant S&T to be incorporated into the fleet in a timely and relevant manner. By avoiding a boom and bust approach to fleet building there would also be the added advantage of attracting, employing, and retaining highly skilled and educated workers – not only within the ship, vehicle, or aircraft building industrial community but also with the CAF itself. This incremental modernization would place a key emphasis on military advantage maximizing the fleets' operational relevance in the demanding environment of tomorrow's battlespace while minimizing the often traumatic costs of whole fleet replacement or upgrade.

[123] In conjunction with calculation of the lowest annual average cost.

	CoA 1 – Replace the Fleet		CoA 2 – Planned Live Extension		CoA 3 – Unplanned Life Extension	
	Strengths	**Weaknesses**	**Strengths**	**Weaknesses**	**Strengths**	**Weaknesses**
Cost Effectiveness	-Decreased maintenance and related downtime -Allows for fleet retirement at optimal retirement age which sees lowest average cost of fleet per year	-Increased initial cost (may be mitigated through accrual budgeting)	-Avoids fiscal shock of new fleet purchase	-Can be long term Increased overall cost (may be mitigated through accrual budgeting of life extension) -Likely increased sustainment demands must be met or cost effectiveness and availability portion of military advantage will be severely degraded	-Reduced initial cost	-Long term overall cost increased -Increased maintenance and other O&M
Timeliness		-Decision to replace fleet must account for the significant amount of time which fleet procurement currently takes – if decision is not made at the appropriate point there may be a capability gap or a force toward CoA 2 or 3		-Decision to conduct a planned life extension must account for the time required to plan for and facilitate sustainment needs to include: stockpiling of parts, increased demand for depot capacity, and other maintenance needs – if decision is not made at the appropriate point there may be a capability gap which will force CoA 3	-No requirement for timely consideration	
Innovation	-Maximum allowance for innovative application of S&T		-Allows for innovative application of S&T if there is a betterment or life cycle extension plan			-No application of S&T
Regional Advantage	-Improved job retention -Maximum investment in regional economy		-Can allow for job retention (through betterment) -Can allow for investment in regional economy (through betterment) as well as the purchase and placement of spare parts and other sustainment facilitators.		-Eventual increased need for maintenance could see unprogrammed investment	-No investment in jobs or regional economy
Military Advantage	-Increased availability -Increased reliability -Potential for increased capability (design dependant) -Improved TIP compatibility		-Some improvement to availability over CoA 3 (with life cycle investment) -Improved reliability over CoA 3 (if sustainment needs met) -Potential for increased capability (extension design dependant)	-Will not account for as many potential improvements to capability and availability as CoA 1		-Outdated capability -Reduced availability

BIBLIOGRAPHY

Arena, Mark V., Irv Blickstein, Obaid Younossi, and Clifford A. Gramach. *Why Has the Cost of Navy Ships Risen? A Macroscopic Examination of the Trends in U.S. Naval Ship Costs Over the Past Several Decades*. Santa Monica: Rand Corporation, 2006.

Arena, Mark V., Obaid Younossi, Kevin Brancato, Irv Blickstein, and Clifford A. Gramach. *Why Has the Cost of Fixed-Wing Aircraft Risen? A Macroscopic Examination of the Trends in U.S. Military Aircraft Costs over the Past Several Decades*. Santa Monica: Rand Corporation, 2008.

Australia. Department of Defence. *Defence Capability Development Handbook 2012*. Canberra: Director, Capability Operations and Plans, 2006.

Australia. Department of Defence. *Defence Capability Development Manual 2006*. Canberra: Director, Skilling, Knowledge, Improvement and Policy, 2012.

Beirnes, Timothy J. *Analysis of Fleet Replacement Lifecycle*. West Palm Beach: South Florida Water Management District, 2012.

Bibona, Sal. Chatham Consulting. "Establishing a Cost Effective Fleet Replacement Program." Last accessed 7 April 2017, http://chathamconsulting.com/publications/replace_files/page19_1.pdf.

Biddle, Stephen. *Military Power: Explaining Victory and Defeat in Modern Battle*. Princeton: Princeton University Press, 2004.

Blakeney, Debbie, Andrew Billyard, Leonard Kerzner, Binyam Solomon, and Paul Chouinard. "Operational Research Tools Supporting the Force Development Process for the Canadian Forces." *Information and Security: An International Journal* 23, No. 1 (2009), 81-98.

Canada. Department of National Defence. A-FD-005-001/AF-003, *The Future Security Environment 2013-2040*. Winnipeg: Chief of Force Development, 2014.

Canada. Department of National Defence. B-GJ-005-500/FP-000, *The Canadian Forces Operational Planning Process (OPP)*. Ottawa: Chief of Force Development, 2008.

Canada. National Defence and the Canadian Armed Forces. "Aerospace Systems." Last accessed 5 May 2017, http://www.forces.gc.ca/en/business-defence-acquisition-guide-2016/aerospace-systems.page.

Canada. National Defence and the Canadian Armed Forces. "Arctic Offshore Patrol Ships." Last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/arctic-offshore-patrol-ships.page.

Canada. National Defence and the Canadian Armed Forces. "Canada First Defence Strategy." Last accessed 4 February 2017, http://www.forces.gc.ca/en/about/canada-first-defence-strategy.page#ql8.

Canada. National Defence and the Canadian Armed Forces. "Canadian Surface Combatant." Last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/canadian-surface-combatant.page.

Canada. National Defence and the Canadian Armed Forces. "CP-140 Aurora Fleet Modernization and Life Extension." Last accessed 27 April 2017, http://www.forces.gc.ca/en/business-equipment/procurement-projects/aurora-cp-140.page.

Canada. National Defence and the Canadian Armed Forces. "Defence Acquisition Guide." Last accessed 14 April 2017, http://www.forces.gc.ca/en/business-defence-acquisition-guide-2016/index.page.

Canada. National Defence and the Canadian Armed Forces. "Defence Resource Management Information System In-Service Support." Last accessed 3 May 2017, http://www.forces.gc.ca/en/business-defence-acquisition-guide-2015/joint-and-other-systems-899.page.

Canada. National Defence and the Canadian Armed Forces. "Defence Purchases and Upgrades Process." Last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/procurement.page.

Canada. National Defence and the Canadian Armed Forces. "Halifax-Class Modernization and Frigate Life Extension." Last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/halifax-frigate.page.

Canada. National Defence and the Canadian Armed Forces. "Joint Support Ship." Last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/joint-support-ship.page.

Canada. National Defence and the Canadian Armed Forces. "Light Armoured Vehicle (LAV) III Upgrade Part 2." Last accessed 14 April 2017, http://www.forces.gc.ca/en/business-defence-acquisition-guide-2016/land-systems-150.page.

Canada. National Defence and the Canadian Armed Forces. "Projects." Last accessed 13 April 2017, http://www.forces.gc.ca/en/business-equipment/projects.page.

Canada. Public Services and Procurement Canada. "National Shipbuilding Strategy." Last accessed 17 February 2017, http://www.tpsgc-pwgsc.gc.ca/app-acq/amd-dp/mer-sea/sncn-nss/index-eng.html.

Canada. Public Services and Procurement Canada. "Summary Report – The Evaluation of Options for the Replacement of the CF-18 Fighter Fleet." Last accessed 14 April 2017, https://www.tpsgc-pwgsc.gc.ca/app-acq/amd-dp/air/snac-nfps/eorfcf18-eorcf18ff-eng.html.

Canada. Royal Canadian Navy. "Interim Auxiliary Oiler Replenishment Capability." Last accessed 8 April 2017, http://www.navy-marine.forces.gc.ca/en/news-operations/news-media-iaor.page.

Canada. Treasury Board. BT59-5/2007, *Canadian Cost Benefit Analysis Guide: Regulatory Proposals.* Ottawa: Treasury Board of Canada Secretariat, 2007.

Chow, Brian G., Richard Silberglitt, and Scott Hiromoto. *Toward Affordable Systems: Portfolio Analysis and Management for Army Science and Technology Programs*. Santa Monica: Rand Corporation, 2009.

Chretien, Jean. *My Years as Prime Minister*. Toronto: Vintage Canada, 2008.

Coyne, Andew. National Post. "How a Guaranteed Minimum Income Could Work in Canada." Last accessed 28 April 2017. http://news.nationalpost.com/full-comment/andew-coyne-how-a-guaranteed-minimum-income-could-work-in-canada.

Defence Industry Daily. "Canada Preparing to Replace its CF-18 Hornets." Last modified [or accessed] 09 February 2017. http://www.defenseindustrydaily.com/canada-preparing-to-replace-its-cf-18-hornets-05739/.

Drew, John G., Kristin F. Lynch, James M. Masters, Robert S. Tripp, and Charles Robert Roll, Jr.. *Options for Meeting the Maintenance Demands of Active Associate Flying Units*. Santa Monica: Rand Corporation, 2008.

Durrell, Steve. "Shipbuilding Centres of Excellence" in *National Approaches to Shipbuilding and Ship Procurement*, edited by Douglas L. Bland, 105-115. Kingston: Queen's University, 2010.

Feng, Wei, and Miguel Figliozzi. "Vehicle Technologies and Bus Fleet Replacement Optimization: Problem Properties and Sensitivity Analysis Utilizing Real World Data." *Public Transport* 6 (2014), 137-157.

Fetterly, Ross, and R. Groves. *Accrual Accounting and Budgeting in Defence*. Kingston: Queen's University, 2008.

Fetterly, Ross. "Shaping Future Procurement Strategies through Canadian Defence Procurement Reform" in *National Approaches to Shipbuilding and Ship Procurement*, edited by Douglas L. Bland, 47-69. Kingston: Queen's University, 2010.

Gandjour, Afschin, and Dirk Muller. "Ethical Objections Against Including Life-Extension Costs in Cost-Effectiveness Analysis: A Consistent Approach." *Appl Health Econ Health Policy* no. 12 (2014), 471-476.

Gimblett, Richard, Paul Manson, Howard Marsh, Pierre Lageux, Peter Cairns, and Brian MacDonald. *Vimy Paper 1: Creating an Acquisition Model That Delivers.* Ottawa: Conference of Defence Associations Institute, 2006.

Gnanarajah, Raj. "Cash Versus Accrual Basis of Accounting: An Introduction." *Congressional Research Service Report* (December 2014).

Government of Japan. "Regionalism Revitalizes Japan." Last modified [or accessed] 03 November 2016. http://www.japan.go.jp/initiatives/regionalism_revitalizes/index.html.

Greenfield, Victoria, and David Persselin. "How Old is Too Old? An Economic Approach to Replacing Military Aircraft." *Defence and Peace Economics* 14, no. 5 (2003), 357-368.

Gunn, Andrea. The Chronicle Herald. "Canada's Navy Dealing with Gaps in Capability While Waiting on New Ships." Last accessed 11 April 2017. http://thechronicleherald.ca/novascotia/1458287-canadas-navy-dealing-with-gaps-in-capability-while-waiting-on-new-ships

Held, Thomas, Bruce Newsome, and Mathew W. Lewis. *Commonality in Military Equipment: A Framework to Improve Acquisition Decisions*. Santa Monica: Rand Corporation, 2008.

Irving Halifax Shipyard. "Ships for Canada." Last accessed 17 February 2017. http://shipsforcanada.ca/.

Hopper, Tristin. National Post. "Own Your Own Army Convoy: Highlights from the Government's Official Auction Site." Last Accessed 14 April 2017. http://news.nationalpost.com/news/own-your-own-army-convoy-highlights-from-the-canadian-governments-official-auction-site.

Jardine, Andrew K.S. University of Toronto Centre for Maintenance Optimization and Reliability Engineering. "Life Cycle Management." Last accessed 07 April 2017, https://www.fcm.ca/Documents/presentations/2010/workshops/Life_Cycle_Management_EN.pdf.

Jobson, N. *Rapid Acquisition of Adaptable Systems*. Portsdown West: UK Defence Science and Technology Laboratory, 2008.

Jones, Shawn R. and George A. Zsidisin. "Performance Implications of Product Life Cycle Extension: The Case of the A-10 Aircraft." *Journal of Business Logistics* 29, no. 2 (2008), 189-215.

Juskalian, Russ. MIT Technology Review. "Practical Quantum Computers." Last accessed 28 April 2017. https://www.technologyreview.com/s/603495/10-breakthrough-technologies-2017-practical-quantum-computers/.

Keating, Edward G., Don Snyder, Mathew Dixon, and Elvira N. Loredo. *Aging Aircraft Repair-Replacement Decisions with Depot-Level Capacity as a Policy Choice Variable*. Santa Monica: Rand Corporation, 2005.

Keating, Edward, and Mathew Dixon. "Investigating Optimal Replacement of Aging Air Force Systems." *Defence and Peace Economics* 15, no. 5 (2004), 421-431.

Kiely, D.G. *Defence Procurement: The Equipment Buying Process*. London: Tri-Service Press, 1990.

Leblanc, Daniel, and Steven Chase. The Globe and Mail. "Sajjan to Lower Expectations for Future Military Purchases." Last accessed 6 May 2017. http://www.theglobeandmail.com/news/politics/sajjan-to-lower-expectations-for-future-military-purchases/article34882029/.

Massachusetts Institute of Technology. MIT Technology Review. "Moore's Law is Dead. Now What?" Last modified [or accessed] 20 February 2017. https://www.technologyreview.com/s/601441/moores-law-is-dead-now-what/.

Markowski, Stefan, and Robert Wylie. "Australian Naval Shipbuilding Strategy 2009" in *National Approaches to Shipbuilding and Ship Procurement*, edited by Douglas L. Bland, 71-103. Kingston: Queen's University, 2010.

McManus, Hugh, A. Haggerty, and E. Murman. "Lean Engineering: Doing the Right Thing Right." *The Aeronautical Journal* 111, no. 1116 (February 2007), 105-114.

McRaven, William H. "The Theory of Special Operations." Thesis and Dissertation Collection, Naval Post Graduate School, 1993.

Mercury Associates. *Fleet Replacement Plan for the City of Prince George*. Prince George: Mercury Associates, Inc., 2014.

Ministry of Defence UK. Strategic Trends Program. *Global Strategic Trends – Out to 2045*. Shrivenham: Development Concepts and Doctrine Centre, 2014.

Mouton, Christopher A., David T. Orletsky, Michael Kennedy, and Fred Timson. *Reducing Long-Term Costs While Preserving a Robust Strategic Airlift Fleet: Options for the Current Fleet and Next-Generation Aircraft*. Santa Monica: Rand Corporation, 2012.

Nossal, Kim Richard. "Late Learners: Canada, the F-35, and Lessons from the New Fighter Aircraft Program." *International Journal* 68, no. 1 (Winter 2012/2013), 167-184.

Department of Defense. Office of the Under Secretary of Defense (Acquisition, Technology and Logistics), Property and Equipment Policy Office. "Military Equipment Useful Life Study – Phase II: Final Report." Washington: Office of the Secretary of Defense, 2008.

Painter, M.K., M. Erraguntia, G.L. Hogg, and B. Beachofski. "Using Simulation, Data Mining, and Knowledge Discovery Techniques for Optimized Aircraft Engine Fleet Management." *Simulation Conference* (Winter 2006), 3-6.

Pugliese, David. Ottawa Citizen. "India Interested in Used RCAF Sea Kings, According to Report." Last accessed 10 April 2017. http://ottawacitizen.com/news/national/defence-watch/india-interested-in-used-rcaf-sea-kings-according-to-report.

Segal, Hugh D. "Finding a Better Way: A Basic Income Pilot Project for Ontario." Last accessed 28 April 2017. https://files.ontario.ca/discussionpaper_nov3_english_final.pdf.

Siddiqui, Huma. Financial Express. "To Fill Urgent Indian Navy Need, Centre Eyes Canada's Used Sea King Helicopters." Last accessed 10 April 2017. http://www.financialexpress.com/india-news/to-fill-urgent-indian-navy-need-centre-eyes-canadas-used-sea-king-helicopters/615283/.

Smit, Wim A.. "Naval Shipbuilding in the Netherlands" in *National Approaches to Shipbuilding and Ship Procurement*, edited by Douglas L. Bland, 35-45. Kingston: Queen's University, 2010.

Sokri, A. Defence R&D Canada. DRDC CORA TM 2009-027. *An Economic Evaluation for CP-140 Aircraft Replacement.* Ottawa: Centre for Operational Research and Analysis, 2009.

Solomon, Binyamin, and Craig Stone. "Accrual Budgeting and Defence Funding: Theory and Simulations." *Defence and Peace Economics* 24, no. 3 (2013): 211-227.

Solomon, Binyam. "An Economics Perspective on a Defence Industrial Policy" in *2010 Canadian Defence Industry at a Crossroads*, edited by Craig Stone, 11-20. Kingston: Queen's University, 2010.

Storey, Ed. "The Success of the Light Armoured Vehicle." *Canadian Military History*20, no. 3 (Summer 2011), 77-80.

Tzeferakos, Steven. "The Canadian Defence Sector: Highlights from the Canadian Commercial Aerospace, Defence, Industrial Marine and Industrial Security Sector Survey, 2007" in *2010 Canadian Defence Industry at a Crossroads*, edited by Craig Stone, 1-9. Kingston: Queen's University, 2010.

Van Bavel, Gregory H. "Balanced Procurement, Military Advantage, and the Canadian Defence Industrial Base" in *2010 Canadian Defence Industry at a Crossroads*, edited by Craig Stone, 40-66. Kingston: Queen's University, 2010.

Walmsley, Robert. "Smart Acquisition: The Next Steps" *RUSI Journal: Royal United Services Institute for Defense Studies* 148, no. 2 (April 2003), 25-28.

Walter, Chip. Scientific American. "Kryder's Law." Last accessed 6 May 2017. https://www.scientificamerican.com/article/kryders-law/.

Wanek-Libman, Mischa. "Maxing Out Life Expectancy." *Railway Track and Structures* 112, no. 10 (October 2016), 34-36.

Weston, William C. "CF-18 Systems Life Extension: Need or Nonsense?" *Canadian Defence Quarterly* 27, no. 2 (Winter 1997), 13-15.

Younossi, Obaid, Mark V. Arena, Robert S. Leonard, Charles Robert Roll, Jr., Arvind Jain, and Jerry M. Sollinger. *Is Weapon System Cost Growth Increasing? A Qualitative Assessment of Completed and Ongoing Programs.* Santa Monica: Rand Corporation, 2007.

Young, Stuart, and Jonathan Davies. "United Kingdom Warship Procurement Strategies: Accident or Design?" in *National Approaches to Shipbuilding and Ship Procurement*, edited by Douglas L. Bland, 1-33. Kingston: Queen's University, 2010.