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# Preventing Fatalities in the CAF

Major Roderick Short

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Major Roderick Short

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**PREVENTING FATALITIES IN THE CAF: A COST-BENEFIT ANALYSIS FOR SAFETY IMPROVEMENTS TO MILITARY EQUIPMENT**

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**ABSTRACT**

Commanding Officers (CO) have a duty of care for the personnel under their command. Their obligation to manage risk is covered in Canadian Armed Forces (CAF) doctrine, and they are empowered to apply controls to reduce risk during operations and training as required. However, a unit CO's ability to manage risk related to military equipment is limited, as Defence Administrative Orders and Directives appoint senior Defence personnel in Ottawa as being responsible for this risk. Furthermore, when risks are identified, securing funding to address materiel risks has historically proven difficult due limited budgets and prioritisation challenges between operational capabilities and safety. Risks should be reduced to the point where any further investment is grossly disproportionate to the level of safety gained. The CAF Elements do not fully capture this concept within their risk management processes, but it is fundamental to ensuring that the government is not exposing its personnel to unnecessary risk while balancing the need to complete the mission. Demonstrating that further investment is, or is not, grossly disproportionate to the reduction in risk requires that a value be placed on preventing a fatality. This is a contentious subject as human life is priceless, yet it is arguably the best way to ensure that resources are expended in a responsible manner across the government. This paper explores the CAF's risk management processes, identifies the lack of direction in policy with regards to risk mitigation, and advocates that a Cost-Benefit Analysis (CBA) be used as a tool to justify funding for safety related materiel projects that reduce risk to life. Treasury Board policy allows for departments to use CBAs along with a value of statistical life, and this paper will recommend that a similar process be adopted within CAF risk management policy.

# PREVENTING FATALITIES IN THE CAF: A COST-BENEFIT ANALYSIS FOR SAFETY IMPROVEMENTS TO MILITARY EQUIPMENT

## CHAPTER 1 - INTRODUCTION

The profession of arms is inherently dangerous and requires a level of risk acceptance during both training and expeditionary operations. Leaders are required to assess risks and must weigh the benefits of activities to their associated costs in order to prevent casualties.[1] Reducing this inherent risk is sometimes possible through the investment of improved equipment such as, but not limited to, new technologies that reduce exposure to emerging threats, improved materials that provide added protection to vehicles or personal body armor, or better design features or systems that reduce the risk of catastrophic loss of military personnel and equipment.[2] Yet for members placed in a position to either procure or manage equipment, expending funds to improve safety can be a challenge to justify as it can often compete with other demands across the Department of National Defence (DND) due to limited and often unstable budgets. The challenge remains how to prioritize the funding for safety related initiatives against other competing demands such as capability improvements.

The CAF has historically struggled to receive adequate defence funding, falling short of the 2% Gross Domestic Product (GDP), North Atlantic Treaty Organization (NATO) target. It is also not uncommon for high level defence priorities to fall victim to political debates resulting in the off ramping or delay to critical equipment needed on the front line.[3] *Strong, Secure, Engaged: Canada's Defence Policy*, provides long term funding commitments over a 20 year horizon which includes long term capability investment, a commitment to grow the CAF, and a clear statement that, "people are at the core of everything the Canadian Armed Forces does to deliver on its mandate." The strategy is clear on its priorities for equipment investment across the elements[4] but it falls short when addressing capital investment to improve equipment safety across Defence.[5] Furthermore, the concept of "safety," is referenced throughout the policy, but only in the context of Canadian society, not the soldiers who operate the equipment.

The *Defence Capabilities Blueprint* (DCB)[6] is subordinate to the Defence Policy and provides a detailed list of approximately 240 major capital projects that are funded

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[1] Department of National Defence, B-GJ-005-502/FP-000, *Risk Management of CF Operations* (Ottawa: DND Canada, 2007), 1-2.
[2] Department of National Defence, B-GJ-005-502/FP-000, *Risk Management of CF Operations* (Ottawa: DND Canada, 2007), 3-3.
[3] F. Melese, A. Richter and B. Solomon, *Military Cost-Benefit Analysis: Theory & Practice* (Abingdon, Oxon: Routledge, 2015), 3.
[4] Royal Canadian Navy, Canadian Army, and Royal Canadian Air Force.
[5] A project for the Canadian Army to upgrade the Light Armored Vehicle fleet to improve mobility and survivability is listed and sets aside $10.1 billion, however other safety related equipment purchases are scant across the policy.
[6] Department of National Defence, Defence Capabilities Blueprint (Ottawa, DND Canada, 2020).

under *Strong, Secure, Engaged*. The searchable database of projects under each Defence Capability Area is updated monthly with links to project websites for additional information. Review of the projects reveals a heavy focus on capability investment with a small number of projects that have a safety element to them.[7] While a small number of safety related projects are listed and funded, they appear to be long standing projects identified several years ago under *Strong, Secure, Engaged*. It is critical that the CAF continue to invest in safety upgrades as part of an overall defence policy, but it is also essential that a mechanism exists to identify emerging in-service risks, and most importantly to provide the appropriate funding avenue to allow for the risk to be mitigated.

The Royal Canadian Air Force (RCAF) and Royal Canadian Navy (RCN) have mature risk management processes specifically aimed at identifying in-service equipment risk, with the output of this process often being the articulation of the risk, combined with a risk mitigation strategy that is accepted by the appropriate authority. Similarly, the Canadian Army (CA) have made significant progress in the area of materiel risk management, leveraging off of the RCAF's process. As detailed below, the latest draft is only awaiting Commander of the Army final approval.

Within three of the primary Elements,[8] the fundamental nature of risk management is consistent. If the funding is available, the process achieves the aim through the Assistant Deputy Minister - Materiel (ADM(Mat))'s investment into safer materiel, however sustainment budgets are often insufficient as mentioned previously, or they often fluctuate during the Fiscal Year (FY) which can lead to safety critical projects being either off ramped or paused. Leaders are therefore required to prioritize equipment projects which may result in a trade-off of safety related modifications for other projects such as projects that provide capability improvements. An appropriate balance needs to be struck so that the CAF has the best equipment to achieve its mandate, while not exposing its personnel to unnecessary and preventable risks. Treasury Board Policy and CAF doctrine provide some guidance on risk management, and how it relates to materiel, which will be discussed in this paper, but it is currently insufficient in determining how leaders can justify and advocate for investments into critical safety upgrades.

This paper proposes a solution of employing a Cost-Benefit Analysis (CBA) to justify improvements in safety for military equipment. Such an approach would allow for a more objective view of safety investments, would be compliant with existing Treasury Board Policy, and may result in safety related modifications being funded instead of operational and capability investments. Such an approach would place an obligation on

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[7] For example, under the Defence Capability Area of Personal Equipment and Protection Systems the Advanced Improvised Explosive Device (IED) Detection and Defeat project is listed along with the Chemical Agent Sensor project and Armoured Combat Support Vehcile project. These projects will certainly improve safety while providing DND with improved capabilities in various threat scenarios.
[8] RCN, CA, and RCAF. CANSOFCOM will be discussed later in this paper, but they essentially rely on the Army's process with different signing authorities for risk.

the government to fund safety improvements regardless of budgetary fluctuations which are bound to happen year to year, and even throughout the Fiscal Year (FY).

To complete a CBA for safety related initiatives, it is necessary to attach a monetary value to preventing a fatality, that is, the value that society places on saving a military member's life or preventing an injury. In order to justify the use of CBAs as an acceptable tool, this paper will first consider the existing risk management process used to articulate and accept technical risk in each of the CAF Elements which will include an explanation of the current shortfall and why the current process falls short regarding monetary investment to reduce risk. It will then explore the problem outside of the CAF and what approach has been taken by other government departments as well as our allies. The final section of the paper will propose the use of a CBA to justify safety related initiatives in defence, and in doing so, will propose that a monetary value be placed on preventing a fatality. It must be noted up front that placing a value on preventing a fatality is not the same as placing a value on a human life. The former considers what society is willing to pay to prevent fatalities given limited budgets across industries as well as societies tolerance for risk, which is different than placing a monetary value on an individual, because human lives are priceless. This concept is explored in more detail in this paper.

## CHAPTER 2 - RISK MANAGEMENT WITHIN THE CAF

### Canadian Armed Forces Risk Management Policy

To comply with the Treasury Board *Framework for the Management of Risk*,[9] DND published the *Defence Enterprise Risk Management Policy*.[10] The policy highlights that the Vice Chief of Defence Staff is the DND/CAF Risk Officer which is then delegated to the Chief of Programme (C Prog). C Prog is then responsible to engage with each of the Commanders of the Elements,[11] hereafter referred to as the Level Ones, to identify, track and mitigate risks within their respective organizations. The policy aims to ensure that, "the risk information is used in the prioritization of activities, resource planning and allocation."[12] The policy captures the four elements of Enterprise Risk Management which are, Corporate Risk Profile, Enterprise Risk Management Function, Enterprise Risk Management in Practice and Continuous Risk Management Learning.

Corporate Risk Profile ensures that risks across the CAF, within each of the Level Ones, are identified thereby enabling risks to be prioritized and resources allocated at the discretion of the Chief of Defence Staff to mitigate or eliminate risks. Specifically, how this is accomplished will be discussed in greater detail below where the risk management process for each of the CAF's Elements are considered. The Enterprise Risk Management Function, and Enterprise Risk Management in Practice ensure that risk management is integrated across the CAF using existing reporting chains. In the latter, it ensures that a common terminology is used by ensuring risks are defined using a combination of severity and probability. Risk managers across the CAF need to articulate both in order to fully define the risk so that the urgency of addressing it can be ascertained. The final element, Risk Management Learning, ensures continuous improvement and any lessons learned are shared across the CAF.

The guidance provided in the policy helps to ensure risks are articulated up the chain of command so that appropriate resources can be allocated. However, as will be discussed below, this is often completed using a qualitative versus a quantitative methodology. A qualitative approach requires judgement to be applied and is often the method chosen when failure rate data is not readily available. As a result, it can be less robust if the probability assessments are not fully justified. The RCAF for example, permit the risk management team to use qualitative definitions for risk probabilities

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[9] Treasury Board Secretariat, *Framework for the Management of Risk*, last modified 19 August 2010, https://www.tbs-sct.canada.ca/pol/doc-eng.aspx?id=19422.
[10] Department of National Defence, *Defence Enterprise Risk Management Policy*, Chief of Programme (Ottawa: DND Canada, 2018).
[11] Commander of the RCAF, Commander of the RCN and Commander of the CA. As will be discussed further, CANSOFCOM is treated slightly different, as the materiel function is imbedded within the Command.
[12] Department of National Defence, *Defence Enterprise Risk Management Policy*, Chief of Programme (Ottawa: DND Canada, 2018).

which can be more straight forward to apply.[13] However, when actual in-service failure rates, or theoretical failure rates, are known up front it is always recommended to apply this data, as it is not refutable. A quantitative approach, underpinned with reliability figures and failure rate data, that is also supported by a qualitative assessment of the risk, using judgement,[14] is broadly seen as the preferred method to justify a risk assessment.

Quantitative risk management also requires that a monetary figure be allocated to the risk reduction initiative both in terms of benefits and costs so that financial resources can be apportioned appropriately. This is a challenge within the current process as risks in the military can often be linked to loss of life, and a monetary value has not yet been established, nor discussed within the CAF. As will also be discussed, there also appears to be inconsistency across the Elements when it comes to the way technical risks to equipment are being managed, the level the risk needs to be mitigated to, who signs off on the risk, and how this risk is tracked. If the risk is significant enough, it will make it to the Corporate Risk Profile to be included in the Department Plan to inform resource management, however less significant risks, even those that involve potential loss of life, will not necessarily make their way to the VCDS level. In order to understand how the most critical risks are evaluated and fed into the Department Plan, as well as how lower-level risks are being managed at the unit, "command," level, it helps to capture how risk is managed doctrinally, as well as how each of the elements identify and manage risk from a process perspective.

**Canadian Armed Forces Doctrine and Orders**

CAF doctrine captures the concept of risk management within the Joint Doctrine Manuals of *CF Joint Force Protection*,[15] as well as *Risk Management for CF Operations*.[16] The CF Joint Force Protection Manual's primary focus is on, "all measures taken to contribute to mission success by preserving freedom of action and operational effectiveness through managing risks and minimizing vulnerabilities to personnel, information, materiel, facilities and activities from all threats."[17] It speaks to the hazards that CAF members face in an inherently dangerous profession and the implications that commanders need to consider within the strategic, operational, deployed, and domestic environments.

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[13] This is discussed in more detail below for each of the Elements.

[14] As an example, judgement might consider a pilot's first hand experience in managing an emergency. It could also consider wider factors surrounding the risk through the risk management process such as the remaining service life of the platform relative to how long a modification would take to design and install on the fleet.

[15] Department of National Defence, B-GJ-005-314/FP-000, *CF Joint Force Protection*, (Ottawa: DND Canada, 2007).

[16] Department of National Defence, B-GJ-005-502/FP-000, *Risk Management of CF Operations*, (Ottawa: DND Canada, 2007).

[17] Department of National Defence, B-GJ-005-314/FP-000, *CF Joint Force Protection*, (Ottawa: DND Canada, 2007), 1-1

Key concepts that are highlighted within the document are that commanders at all levels are responsible for the health and safety for their personnel, clearly stating that this is a "Command Responsibility." [18] Furthermore, it goes on to explain the legal aspects of Force Protection in that, "activities and measures during the operation must be regulated in order to protect people and property from unlawful or unnecessary damage or injury."[19] While captured under a legality clause in the manual, it is implied that the commander's discretion is relied upon to determine how this is accomplished, with no actual legal tools for which commanders can leverage in order to obtain the resources they need to further reduce risks if required. The manual also discusses risk management from a standpoint of identifying risks and mitigating them to an appropriate level, again which is subject to the Commander's discretion. It is, "the commander [who] makes the final decision on the extent of controls and measures, given the mission, the risk, resources available and command considerations."[20] This wording is, however, consistent with the fundamental need for risks to be both tolerable and As Low As Reasonably Practicable (ALARP), two concepts which will be discussed in greater detail below.

The Joint Doctrine Manual of *Risk Management for CF Operations*, provides additional guidance on the risk management process covering the military planning process. Again, the concept of risk tolerability is made clear in that risks should only be taken that contribute to the successful completion of the mission or task, and that the commander should evaluate and implement risk controls in order to reduce risk whenever possible.[21] This includes Engineering Controls which adapt new technology to reduce risk to personnel, or new materials that provide additional protection. Again though, it is up to the commander's discretion and the manual does not provide a legal or policy framework for which to leverage off of to advocate for additional resources to reduce risk to personnel if existing budgets are insufficient.

Furthermore, because the manual is heavily focused on the process to assess and manage operational risk, its focus is not targeted towards mitigating equipment risk specifically. The role that equipment plays within the operational environment is clearly critical as it enables commanders to fight, therefor from an operational risk management perspective, the manual focusses primarily on the impact to the operation if the particular equipment is lost. While the document could be interpreted to also include the risk that the equipment poses to personnel, there is insufficient guidance within the manual to

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[18] Department of National Defence, B-GJ-005-314/FP-000, *CF Joint Force Protection*, (Ottawa: DND Canada, 2007), 1-9
[19] Department of National Defence, B-GJ-005-314/FP-000, *CF Joint Force Protection*, (Ottawa: DND Canada, 2007), 1-10
[20] Department of National Defence, B-GJ-005-314/FP-000, *CF Joint Force Protection*, (Ottawa: DND Canada, 2007), 2-4.
[21] Department of National Defence, B-GJ-005-502/FP-000, *Risk Management of CF Operations*, (Ottawa: DND Canada, 2007).

determine when, and for what purpose, an equipment specific risk assessment would be completed.

It should be noted that the ALARP concept is covered briefly within the manual, stating that commanders should, "Accept Risk When Benefits Outweigh the Cost. The process of weighing risks against opportunities and benefits helps to maximize mission success. Balancing costs and benefits is a subjective process and must remain a commander's decision." [22] While it is acknowledged that the manual addresses the balance of cost versus benefits, this is the only mention of the concept in the manual and therefore specific guidance on how to apply it, or to what ends, is lacking. Furthermore, the final statement is clear that the balancing of costs and benefits is subjective, which, according to the argument made in this paper, is false. As will be discussed in Chapter 3, a CBA can be used to objectively evaluate costs and benefits.

Even though the ALARP concept is covered in *Risk Management for CF Operations,* and considering the *CF Joint Force Protection* document places the responsibility of risk management on commanders, guidance is still insufficient when it comes to building an argument for funding safety initiatives based on doctrine alone. Instead, CAF Orders, and already established procedures within each of the Elements are likely the most effective methods currently used to help justify spending on safety initiatives due to their more accepted and widely understood use across ADM(Mat) and each of the Elements.

It is worth noting that a CAF wide order exists which appoints Level Ones as being responsible for the technical assurance of Materiel. As captured in the Defence Administrative Orders and Directive (DAOD) 3035-0, "responsibility and accountability for the…risk management of defence systems and equipment [is] shared between ADM(Mat) and the commanders of the Royal Canadian Navy, Canadian Army, [and] Royal Canadian Air Force."[23] Further details on the responsibilities of each of the Level Ones is detailed in Annex A. While the DAOD is thin on details on how risk can be managed and mitigated for defence equipment, having positional accountability across Level One organizations is fundamental to establishing consistency in equitable resource allocation to address risks across the Elements. Establishing consistency also requires an understanding of the risk management process of each of the Elements to ensure they apply the same fundamental process for managing equipment risk.

As will be explained in the following section, both the RCN and RCAF have mature risk management programs, albeit neither have a mechanism to objectively justify investments in safety upgrades to reduce risk to their personnel. Similarly, the CA has

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[22] Department of National Defence, B-GJ-005-502/FP-000, *Risk Management of CF Operations*, (Ottawa: DND Canada, 2007), 2-2.
[23] Department of National Defence, DAOD 3035-0, Material Assurance, Government of Canada, last modified 13 May 2021, https://www.canada.ca/en/department-national-defence/corporate/policies-standards/defence-administrative-orders-directives/3000-series/3035/3035-0-materiel-assurance.html, Section 3.

leveraged off of RCAF policy, and while it is starting to mature their materiel risk reduction policy, an objective process does not exist to justify safety upgrades to equipment. While late to adopt materiel risk management processes, the CA have now identified the need to address the risk to personnel that failing materiel can have. As will be detailed below, Canadian Special Operations Forces Command (CANSOFCOM) are leveraging off of the emerging policy being developed by the CA. Where CANSOFCOM differ is that they do not rely on ADM(Mat) for materiel assurance, management or directives for equipment, which is unique to CANSOFCOM, as this function is retained within the organization. This paper will now look at each of the Elements risk management processes in turn, starting with the RCAF.

**Royal Canadian Air Force (RCAF)**

The RCAF is arguably the expert Element within the CAF when it comes to risk management of equipment. This is simply due to the fundamental nature of operating an aircraft where it is not possible to simply pull over and wait for assistance when a system failure occurs. If a system on the aircraft fails, it can have deadly consequences, and while aircraft design ensures that a single system cannot result in the catastrophic loss of the aircraft, situations will inevitably arise where in-service evidence unveils below standard reliability targets for primary or backup systems, systems degrading over the lifespan of the aircraft, or industry introducing new technology which can improve the safety baseline of the aircraft. Assessing this risk, and most importantly, the risk to life of the people operating the aircraft, is done using the *Airworthiness Risk Management Process*.[24]

The *Airworthiness Risk Management Process* is a decision-making tool that is used jointly by technical[25] and operational staff[26] to manage risks that reduce the level of safety of the aircraft, or its survivability equipment, to levels below that accepted during initial Certification.[27] The process relies fundamentally on maintaining an Acceptable Level of Safety (ALOS), that is, "the minimum safety goals established by the Regulator, generally defined in terms of the probability and severity of an aircraft accident occurring."[28] The ALOS may, therefore, be slightly different from one aircraft to the next as the certification requirements vary between aircraft types. By approving the Certification Basis, the Regulator, on behalf of the Minister of National Defence, has

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[24] Department of National Defence, *EMT01.003 Airworthiness Risk Management Process*, dated 7 Feb 2022.
[25] The Technical Airworthiness staff with the Director General Aerospace Equipment Program Management Division.
[26] The Operational Airworthiness Staff reside in 1 Canadian Air Division. As per EMT01.003, "1 CAD Fleet Staff are dual-hatted and perform two roles – Operational Airworthiness and Fleet Readiness. For their OA role, these personnel are responsible for operational aspects of the airworthiness program, ensuring that aeronautical products can be operated safely."
[27] This extends in service to include any subsequent design changes brought in after the aircraft entered service.
[28] Department of National Defence, *EMT01.003 Airworthiness Risk Management Process*, dated 7 Feb 2022, 2

"Accepted," the Level of Safety of the aircraft type. This is an important concept because any subsequent changes to the aircraft type must maintain the same ALOS baseline.[29]

When a risk is identified the technical staff will document the situation that causes the decrease in safety, the root cause, and the various hazard effects considering the many scenarios that could result given the emergent risk. Each of the hazard effects are then assigned a severity and probability assessment which produces an overall Risk Index.[30] The definitions used by the technical staff for severity and probability assessments are listed in Annex B. The Risk Index is, "selected according to the intersection of severity and probability in the [Risk Index Table]."[31] So stated simply, the risk associated with a given hazard effect is a combination of severity and probability and is visually displayed on a color-coded chart identifying the levels of risk within the Risk Index Table shown in Table 2.1 below.

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[29] While it is uncommon to change the Certification Basis, any subsequent change may change the ALOS levels.
[30] Department of National Defence, *EMT01.003 Airworthiness Risk Management Process*, dated 7 Feb 2022, 14
[31] Department of National Defence, *EMT01.003 Airworthiness Risk Management Process*, dated 7 Feb 2022, 15

**Table 2.1 – Royal Canadian Air Force Risk Index Table**

| HAZARD | | | CATEGORY | | | | |
|---|---|---|---|---|---|---|---|
| SEVERITY / PROBABILITY | | | A | B | C | D | E |
| | | | Catastrophic | Hazardous | Major | Minor | Negligible |
| LEVEL | 1 | Frequent | A1 Extremely High | B1 Extremely High | C1 Medium | D1 Low | E1 |
| LEVEL | 2 | Probable | A2 Extremely High | B2 High | C2 Low | D2 | E2 |
| LEVEL | 3 | Remote | A3 High | B3 Medium | C3 | D3 | E3 |
| LEVEL | 4 | Extremely Remote | A4 Medium | B4 | C4 | D4 | E4 |
| LEVEL | 5 | Extremely Improbable | A5 | B5 | C5 | D5 | E5 |

Acceptable Level of Safety

Source: Department of National Defence, *EMT01.003 Airworthiness Risk Management Process* (Ottawa: DND Canada, 2022), 32

The level of sign off of the hazard is proportionate to the risk as shown in Table 2.2 below. That is, Extremely High Risk requires the Chief of the Air Staff to accept the risk, while Medium Risk requires that the 1 or 2 Canadian Air Division Director accepts the risk as the Operational Command Risk Acceptance Authority (OCRAA), depending on the fleet.[32]

[32] Department of National Defence, *EMT01.003 Airworthiness Risk Management Process*, dated 7 Feb 2022, 19

**Table 2.2 – Approval and Acceptance Authorities per RARM Risk Index**

| Current Risk Index | TAA Approval Authority * | OAA Approval Authority**** | Operational Command Risk Acceptance Authority**** |
|---|---|---|---|
| **Extremely High** | TAA<br>Independent TAA Staff Review required ** | OAA | CAS |
| **High** | SDE<br>(AI in absence of SDE)<br>Independent TAA Staff Review required ** | Senior Operational Airworthiness Manager<br>(SOAM) | Comd 1 or 2 CAD<br>(fleet dependent) |
| **Medium** | SDE<br>(AI in absence of SDE) | Divisional Operational Airworthiness Manager<br>(DOAM)<br>(fleet dependent) | 1 or 2 CAD Div HQ Director<br>(fleet dependent) |
| **Low** | AI | | |
| **ALOS** | AI | Assigned<br>Section Head *** | Not Required |

Source: Department of National Defence, *EMT01.003 Airworthiness Risk Management Process* (Ottawa: DND Canada, 2022), 19

At the same time the risk is presented to the OCRAA, a Risk Control Plan will also present options to mitigate the risk. As per the process:

> …The Risk Control Plan presents options for controlling the risk, evaluates those options, and selects the preferred option(s); the implementation plan of this selected option(s) is then described. The selected options are a recommendation to the OCRAA, who may then accept or reject some or all of the options. As much as possible, the intent is to maintain the aircraft/fleet within an ALOS and to avoid, through the implementation of risk control measures, operating the aircraft/fleet with an Airworthiness Risk index that is not within an ALOS.[33]

It is therefore clear that the RCAF *Airworthiness Risk Management Process* aims to have risks mitigated down to an ALOS threshold. As stated above, controls may be put in place to reduce the risk based on the benefit that the activity brings. While not explicitly covered in process, this implies that the RCAF use the concept of Tolerability, that is, the risk that personnel are being exposed to must be worth it in terms of the benefit that the activity brings, otherwise an appropriate control would not have been put in place. Note as well that the OCRAA is accepting the risk based on how the aircraft is intended to be operated, that is, after the point at which the controls are put in place.

The RCAF process does not require that risk be further mitigated below ALOS as the goal is to maintain the baseline that was established during certification. The concept of ALARP, therefore, does not currently apply within the RCAF, yet it could be argued

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[33] Department of National Defence*, EMT01.003 Airworthiness Risk Management Process*, dated 7 Feb 2022, 16

that an opportunity exists to adopt the concept as relatively minor investments in equipment could greatly reduce risks, even when below the ALOS threshold.

The process does not direct nor guide how financial resources should be distributed between operational capability and safety. Instead, the risks are managed at a high enough level within the technical and operational staff that financial resources can be allocated if the person holding the risk wishes to invest in a design change to mitigate it further. This is currently done using judgement and close discussions between technical and operational staff. While ADM(Mat) manages the sustainment budgets and execute design changes on their respective fleets, the Regulator will not usually get involved unless a risk is deemed so significant that it violates the original certification basis, or in the event an emergent risk that is higher than ALOS, is not being sufficiently mitigated or managed.

The fundamental issue is there is no method to directly compare safety related modifications across all of the fleets from a quantitative perspective. In a time of reduced budgets and different contract frameworks across each of the fleets, this has the potential to leave some fleets with inadequate funding to address safety concerns. Adopting a CBA would help solve this issue as it would allow safety related projects to be directly compared against one another using a standardized and quantitative process. As will be seen below, the RCAF is not the only Element that lacks a quantitative method to compare projects. The RCN and CA have established risk management processes, albeit at different states of maturity, but neither have a process for quantitatively justifying safety upgrades.

**Royal Canadian Navy (RCN)**

The RCN has a robust risk management framework and recognizes in policy that military personnel are subjected to dangerous situations in their day to day work. The RCN have a Technical Order governing *Naval Materiel Risk Management*[34] which sets out the requirements specifically aimed at risk to materiel, and is subordinate to, and supports, the CAF's *Defence Enterprise Risk Management Policy*,[35] discussed above. The Technical Order also explains the concept of tolerable risk, where the authority should only accept the risk when the benefit of the activity outweighs the cost. [36]

When assessing risk, the RCN uses a standard five by five matrix, titled the Naval Material Management Risk Matrix. The risk is assessed by determining the severity and

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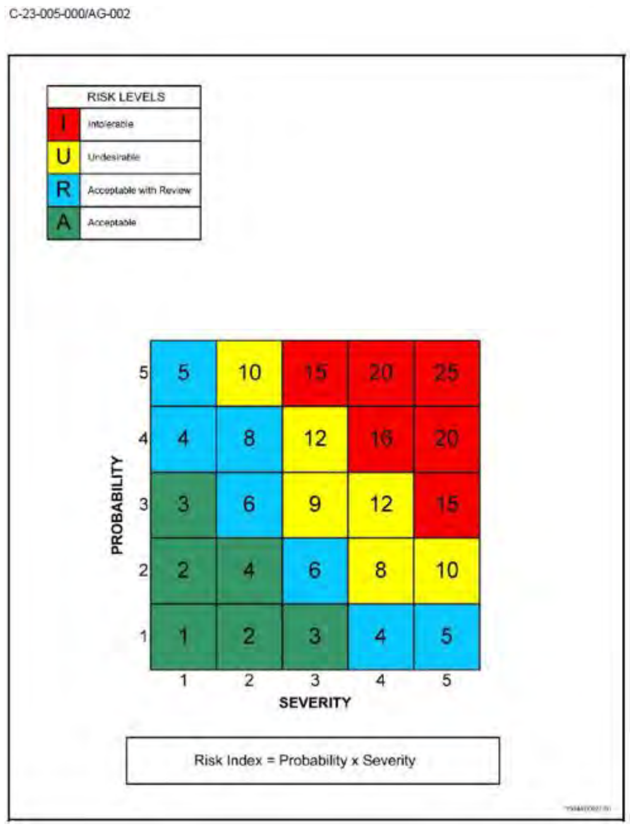
[34] Department of National Defence, C-23-005-000/AG-002, *Naval Materiel Risk Mangagement* (Ottawa: DND Canada, 2013, I.
[35] Department of National Defence, *Defence Enterprise Risk Management Policy*, Chief of Programme, 26 July 2018.
[36] Department of National Defence, C-23-005-000/AG-002, *Naval Materiel Risk Mangagement* (Ottawa: DND Canada, 2013, 1-6.

probability of the situation, and then once mitigation is applied, the level of risk can be plotted on the matrix shown in Table 2.3 below.

**Table 2.3 – Royal Canadian Navy Risk Index Table**




Source: Department of National Defence, C-23-005-000/AG-002, *Naval Materiel Risk Management* (Ottawa: DND Canada, 2013), 3-9.

Risks in the green region are deemed to be acceptable and do not require further mitigation while risks in the blue region are acceptable but require review. This review may include further mitigation using the ALARP principle, and requires that the activity be assessed to ensure the benefit of the activity is worth the risk. Risks in the yellow region should be mitigated and the ALARP process applied. Risks in the red region are deemed to be intolerable.

In accordance with Naval Order 3001-1,[37] the authority to then accept the level of risk along with proposed mitigation rests with different authorities depending on whether the risk stems from a deviation from Design Intent during a configuration change, a deviation from the Certification Baseline of the ship or ship class, operation of the ship

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[37] Department of National Defence, NAVORD 3001-0, *In-Service Naval Materiel Risk Management – Policy* (Ottawa: DND Canada, 2021.

outside of its Certification Baseline, or when the materiel state of the ship is in question.[38] The approval authorities for each of these categories are provided below in Table 2.4 – Royal Canadian Navy Post Mitigated Risk Level Technical Endorsement and Approval Levels. Notes within the Matrix can be found in Annex C.

**Table 2.4 – Royal Canadian Navy Post Mitigated Risk Level Technical Endorsement and Approval Levels**

| In-Service Risk Management Scenario | RMR Risk Level (Post Mitigated) | Technical Endorsement | Technical Approval |
|---|---|---|---|
| 1. Risk Management of the Basis of Design and Design intent | Acceptable | SA (see note 1) | DA (see note 1) |
| | Acceptable with Review | SA (see note 1) | DA (see note 1) |
| | Undesirable | SA Functional Director (DNPS, DNCS) | DA |
| | Intolerable | Naval Materiel Authority | Naval Materiel Authority |
| 2. Risk Management of the Certification Base Line and Certification Plan | Acceptable | DA | Agent de certification |
| | Acceptable with Review | DA | ARMN |
| | Undesirable | DA | ARMN |
| | Intolerable | Naval Materiel Authority | Naval Materiel Authority |
| 3. Risk Management of Operational Departures from the Certification Baseline | Acceptable | EO | CO |
| | Acceptable with Review | DCOS FTA (see note 2) | CO |
| | Undesirable | DA | CCFL/P, MCE(W), D/MCC (See notes 3 & 4) |
| | Intolerable | Naval Materiel Authority | N00 / MCC (See note 3) |
| 4. Risk Management of Mission Readiness and Performance | Acceptable | EO | CO |
| | Acceptable with Review | DCOS FTA (see note 2) | CO |
| | Undesirable | DA | CCFL/P, MCE(W), D/MCC (See notes 3 & 4) |
| | Intolerable | Naval Materiel Authority | N00 / MCC (See note 3) |

Source: Department of National Defence, *NAVORD 3001-0, In-Service Naval Materiel Risk Management – Policy* (Ottawa: DND Canada, 2021), 9.

It must be noted that the Technical Order also explains the need for risks to be assessed and reduced to the point where they are considered ALARP. It is explained that fundamentally, "risk reduction should continue, even lower than the acceptable level, as long as the effort in cost or time is not disproportionate to the benefit or opportunity gained." [39] The concept is shown graphically in Figure 2.1 below.

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[38] Department of National Defence, NAVORD 3001-0*, In-Service Naval Materiel Risk Management – Policy* (Ottawa: DND Canada, 2021, 6.
[39] Department of National Defence, C-23-005-000/AG-002, *Naval Materiel Risk Mangagement* (Ottawa: DND Canada, 2013, 1-7.

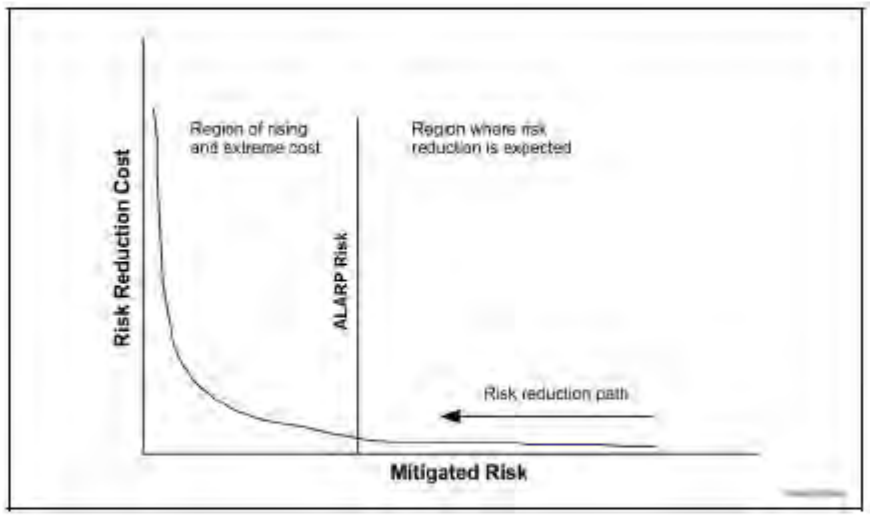


**Figure 2.1 - ALARP Principle**

Source: Department of National Defence, C-23-005-000/AG-002, *Naval Materiel Risk Management* (Ottawa: DND Canada, 2013), 1-8.

The Technical Order expands on the ALARP concept by explaining that it is possible to overspend on risk reducing measures for risks that are not deemed to be of concern using the process, and that these measures should not be implemented, or removed. This has the obvious benefit of freeing up funding for projects that could have a much greater impact on reducing risk to personnel in other areas of the RCN. [40]

The *Naval Materiel Regulation for Surface Ships* expands on the ALARP concept further by stating that, "a risk is ALARP when it has been demonstrated that the cost of any further risk reduction, where the cost includes the loss of defence capability as well as financial or other resource costs, is grossly disproportionate to the benefit obtained."[41] It is interesting to note that the cost includes the loss of defence capability, yet it is not clear how to account for personnel. Furthermore, the concept of grossly disproportionate is not expanded upon further. To understand this concept, the United Kingdom's Ministry of Defence process is captured in Chapter 3 below, because it not only assigns a monetary value to human life, but it also provides guidance on how to determine when a project cost is grossly disproportionate to its benefits.

The RCN's risk management process is fundamentally similar to the RCAF in terms of risk identification, risk management, and risk mitigation. The two processes differ in the sense that the RCN requires the application of risk reduction using the

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[40] Department of National Defence, C-23-005-000/AG-002, *Naval Materiel Risk Mangagement* (Ottawa: DND Canada, 2013), 1-9.
[41] Department of National Defence, C-23-005-000/AG-001, Naval Materiel Regulation for Surface Ships (Ottawa: DND Canada, 2013), GL-E-1.

ALARP concept for risks that are higher than, "acceptable." In contrast the RCAF requires risk reduction to the level of ALOS but does not require that risks be mitigated until the cost is grossly disproportionate to the safety benefits. Neither process identifies how risks can be compared across their respective Elements to prioritize them given limited budgets.

The in-service risk management process within the CA, on the other hand, leverages heavily off of the RCAF process. While not nearly as mature as the RCAF or RCN, this also presents somewhat of an opportunity as the process is very much in development with an initial policy published and a second iteration under review. This provides an opportunity to adopt concepts such as ALARP and risk mitigation using a CBA and attaching a value to human life.

**Canadian Army (CA)**

Following the appointment of the Director General Land Equipment Management (DGLEPM) as the lead to develop a risk management framework for materiel risks within the Land domain, the CA implemented its initial policy for Land Material Assurance – Safety Risk Coordination on 29 October 2018.[42] As mentioned previously, the program borrowed heavily from the RCAF's Airworthiness Program by establishing risk as a function of severity and probability, the definitions of which were adopted and slightly amended from the RCAF's program. Importantly, the initial program establishes a framework and process to identify, analyze, and develop a control plan for equipment risks. Residual risks then have a level of approval for which they could be accepted, and the risk tracked in a risk register.[43]

This process was matured and a new process has emerged that is now only awaiting the Commander of the Army sign off.[44] The new process titled *DGLEPM System Safety Program* develops the risk management process further by leveraging the guidance in DAOD 3035 which states that Operational Commanders and ADM(Mat) both share materiel assurance responsibilities through life but that it is DGLEPM's responsibility to ensure the equipment is "safe to operate and can be operated safely."[45]

When risks are identified, they follow a similar process to that of the RCAF and RCN, where the severity and probability of a hazard event are determined using the definitions provided in Annex D. The post mitigated risk is then plotted on the risk index

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[42] Department of National Defence, *10001-1 Land Materiel Assurance – Safety Risk Coordination* (Ottawa: DND Canada, 2018).
[43] Department of National Defence, *10001-1 Land Materiel Assurance – Safety Risk Coordination* (Ottawa: DND Canada, 2018), Annex B.
[44] Department of National Defence, *10001-1 DGLEPM System Safety Program* (Ottawa: DND Canada, draft).
[45] Department of National Defence, *10001-1 DGLEPM System Safety Program* (Ottawa: DND Canada, draft), 1.

shown in Table 2.5 below, with any risk that is at, or below, an Acceptable Level of Risk (ALOR) not proceeding further to a Record of Risk Management (RORM).

**Table 2.5 – Risk Index Table Canadian Army**

| HAZARD SEVERITY / PROBABILITY | | | CATEGORY A | B | C | D | E |
|---|---|---|---|---|---|---|---|
| | | | Catastrophic | Hazardous | Major | Minor | Negligible |
| LEVEL | 1 | Frequent | A1 Extremely High | B1 Extremely High | C1 Medium | D1 Low | E1 ALOR |
| | 2 | Probable | A2 Extremely High | B2 High | C2 Low | D2 ALOR | E2 ALOR |
| | 3 | Remote | A3 High | B3 Medium | C3 ALOR | D3 ALOR | E3 ALOR |
| | 4 | Extremely Remote | A4 Medium | B4 ALOR | C4 ALOR | D4 ALOR | E4 ALOR |
| | 5 | Extremely Improbable | A5 ALOR | B5 ALOR | C5 ALOR | D5 ALOR | E5 ALOR |

Source: Department of National Defence, *10001-1 DGLEPM System Safety Program* (Ottawa: DND Canada, draft), Annex C.

Like the RCN and RCAF processes, the level of risk acceptance is proportional to the level or risks with Extremely High risks needing both ADM(Mat) and the Comd Canadian Army accepting the risk as shown in Table 2.6 below.

**Table 2.6 – Canadian Army Safety Risk Acceptance Signing Authorities**

| Risk Level | Technical Authority | Operational Authority: Canadian Army | Operational Authority: Other |
|---|---|---|---|
| ALOR | Fleet Materiel Authority (FMA) | CA G34 | L4 Comd (LCol / Cdr) |
| LOW | FMA | CA G34 | L4 Comd (LCol / Cdr) |
| MEDIUM | Director | CA G3 | L3 Comd (Col / Capt(N)) |
| HIGH | DGLEPM | COS A Ops | L2 Comd (BGen / Cmdre) |
| EXTREMELY HIGH | ADM(Mat) | Comd CA | L1 Comd (LGen / VAdm) |

Source: Department of National Defence, *10001-1 DGLEPM System Safety Program* (Ottawa: DND Canada, draft), Annex A.

Also instrumental within the new process is the concept of ALARP where it is stated that, "risk of personal injury and death or materiel damage and losses is reduced to a level As Low As Reasonably Practical (ALARP)."[46] While the process does not expand on how to assess what it means for a risk to be mitigated to ALARP, it does go on to say that "the effort spent on materiel safety must be proportional to the risk." [47] The statement is subjective, but in theory by simply stating the ALARP principle, this opens the door to allow a CAF member from an Operational Command or DGLEPM to build an argument using a CBA and referencing the policy as leverage. If one then considers the RCN's explanation of ALARP, captured above, that, "risk reduction should continue, even lower than the acceptable level, as long as the effort in cost or time is not disproportionate to the benefit or opportunity gained," [48] then surely a quantitative financial argument can be made using a CBA to advocate for funding to improve safety.

While this requires the individual in the land domain to conduct further research into the ALARP concept, for example by referencing the definition from the RCN policy, an opportunity exists to exploit the use of a CBA to justify safety improvements. An opportunity also exists for the policy to continue to be matured. As it is still in draft form and evolving quickly to catch up to the RCAF and RCN, an opportunity exists for DGLEPM to further define the ALARP concept within their System Safety Program. It should also be noted that the System Safety Program for materiel in the land domain also applies to any pieces of common equipment being used within CANSOFCOM.

**Canadian Special Operations Forces Command (CANSOFCOM)**

CANSOFCOM processes are not openly published. Engagement with CANSOFCOM[49] revealed that the organization leverages from the CA process described above, which includes the adoption and slight modification of the CA RORM template. As described above, DAOD 3035-0 states that equipment risk is shared between ADM(Mat) and the other Elemental Commanders, yet the DAOD also makes clear that CANSOFCOM issue their own materiel assurance policies and guidelines and that they govern materiel assurance for equipment that is unique to their organization. For materiel that is shared with the CA, CANSOFCOM will remain a stakeholder for that equipment but the materiel assurance, management, policies, etc. remains with the CA which adheres to the process described above. This includes the process for risk management as well as the risk index table, Table 2.5 above.

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[46] Department of National Defence, *10001-1 DGLEPM System Safety Program* (Ottawa: DND Canada, draft), 2.
[47] Department of National Defence, *10001-1 DGLEPM System Safety Program* (Ottawa: DND Canada, draft), 2.
[48] Department of National Defence, C-23-005-000/AG-002, *Naval Materiel Risk Mangagement* (Ottawa: DND Canada, 2013, 1-7.
[49] CANSOFCOM Equipment Management Team Lead, telephone conversation with author, 10 January 2023.

Because equipment risk in CANSOCOM is governed internally; that is, both the Technical Authority and Operational Authority are within CANSOFCOM, and the fact that they are able to self-govern materiel risk, the levels of risk acceptance are different than that of the CA as captured in Table 2.7 below.

**Table 2.7 – CANSOFCOM Risk Acceptance Level for Materiel Risk**

| Risk Level | Technical Authority | Operational Authority CANSOFCOM |
|---|---|---|
| LOW | EMT Leader (ENG-05 or LCol and above) | J3 Ops |
| MEDIUM | Director Force Sustainment (DFS) | Director SOF Operations (DSO) |
| HIGH | Director Force Sustainment (DFS) | DCOMD |
| EXTREMELY HIGH | Director Force Sustainment (DFS) | COMD |

Source: CANSOFCOM Equipment Management Team Lead, email to author, 10 January 2023.

It should be noted that even though CANSOFCOM is a relatively small unit and is considered to be a flat organization, the sign off levels for risk are very similar to that of the CA. For example, comparing Tables 2.6 and 2.7 reveal that the risk acceptance level for Low Risk is at the Lieutenant Colonel rank for both organizations, while Extremely High Risk has the respective Commanders as the Operational Authority for risk acceptance.

On the other hand, the CA and CANSOFCOM differ greatly in terms of per capita funding, and this is reflected in higher level strategy. From the government's Strategy for Canada's Special Operations Force, "CANSOFCOM [is required to be] an action-oriented organization supported by flexible resources…enabled by technology, empowered by flat teams built around end-to-end accountability."[50] Resources and funding for CANSOFCOM tend to be at a level that enables the organization to adopt technology rapidly and that includes technology that allows their operators to carry out their duties as safely as possible.

For this reason, CANSOFCOM will not be considered further in this paper as it is assumed that materiel initiatives that could reduce safety are funded accordingly and not at the expense of capability improvements. It is assumed that CANSOFCOM have sufficient funding for safety and capability and therefore a CBA to reduce the risk to personnel would provide little value.

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[50] Department of Defence, Beyond the Horizon, A Strategy For Canada's Special Operations Forces in an Evolving Security Environment (Ottawa: DND Canada, 2020), 31.

For the remainder of the CAF, however, a CBA provides an opportunity to justify funding for safety improvements. As the next section will explore, the use of a CBA requires a discussion on the morality of placing a value on human life, a review of methods used in wider literature to assign a value on human life, as well as existing Treasury Board policy on this approach. These points will be explored in the next chapter.

## CHAPTER 3 - REDUCING RISK USING A COST-BENEFIT ANALYSIS

Many people would argue that it is not possible to place a value on a human life. From a logical and morality perspective, this argument makes sense because the money is no good to an individual that has passed away. Similarly, many people would say the same about their spouse or immediate family, in that their lives are priceless and no amount of money could replace them. The concept that human life is priceless is therefore valid. However, such an approach would prevent society from prioritizing resources accordingly in an effort to reduce risk in those areas that see the greatest rate of death or injury. [51]

If government organizations treated human life as having an infinite value, projects that improve safety could easily be focused on professions that see the highest numbers of deaths. While this may seem appropriate on the surface, consideration must be given to the fact that some higher risk professions may need drastic investments in funding to only reduce the risk by a negligible amount, while other less risky professions may only require relatively small investments that will translate to significant safety gains. For example, Employment and Social Development Canada (ESDC) is responsible for the labor market in Canada at the federal level. Their 2020 annual report[52] contains a list of deaths by industry and states that Air Transportation as one of the most dangerous industries to work in,[53] with the majority of fatalities related to small aircraft accidents rather than large commercial aircraft crashes.[54] Technology exists to improve safety in this industry by installing a Ballistic Parachute Recovery System (BPRS) on the aircraft, so in the unlikely event of an emergency such as an engine failure, the pilot could release the BPRS and land safely if they were not able to find a field to perform an emergency landing. The drawback to these systems is the cost involved to purchase and install them. Exact pricing on these systems is difficult to find but it is estimated to be more than $15,000 CAD for a small bush plane like a Cessna 182[55], and increasing based on the aircraft's maximum takeoff weight.

The $15,000 cost per aircraft for a small bush plane company could be considered high, and an operator may choose to take their chances without a BPRS, noting that an engine failure is one of many possible dangers within the industry. It is clear in this case that the risk is reduced slightly with the installation of a BPRS, but the cost could be seen

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[51] "THE WAY WE LIVE NOW: 3-28-04; the Human Factor: THE WAY WE LIVE NOW: 3-28-04." *New York Times (Online)*2004.

[52] Government of Canada, Employment and Social Development Canada, *2020 Annual Report – Occupational Injuries in the Canadian Federal Jurisdiction* (Ottawa: ESDC Canada, 2020).

[53] Government of Canada, Employment and Social Development Canada, *2020 Annual Report – Occupational Injuries in the Canadian Federal Jurisdiction* (Ottawa: ESDC Canada, 2020), 9.

[54] One needs to simply consider the frequency of commercial aircraft accidents within Canada. Commercial airliner accidents are not an annual occurrence, yet the ESDC reports that there were 11 fatalities in 2019.

[55] BRS Aerospace website lists the pricing for parachute systems for ultralight aircraft with several options under $10,000. Larger parachutes require a custom quote for the aircraft type. Website last accessed 24 January 2023, https://brsaerospace.com/experimental-aircraft-catalog-e/#1541099356582-2dbe45f2-985d.

as significant for small operators. Looking at other professions, however, it can be seen that very small investments in safety initiatives can have a more significant impact on reducing risk, such as that of professional roofers.

Taking the profession of a roofer into consideration, a profession with less deaths per year than bush pilots, the fatality rate can be more easily reduced with a much smaller investments in safety equipment. A recent court case in 2019 determined that the deaths of three roofers in Southern Ontario could have easily been prevented with the investment of fall arrest gear, drones and telescopes:[56] a cost in the neighborhood of $500 CAD. While a CBA would be required to fully compare these two examples on a per capita and annualized basis, it highlights the fact that relatively small investments in lower risk industries can significantly improve safety, over large investments in higher risk professions.

The same concept applies to the CAF, in that some military professions may require relatively small investments in safety to drastically reduce risk, while other professions could be at high risk but require significant investments to marginally reduce the risk. For example, investment into a new zero-zero ejection seat for the Snowbird Tutor aircraft would have significant cost, but only marginal safety gains for an aircraft that is nearing the end of its in-service life. On the other hand, investing in the latest body armor for the CA could be much more cost effective relative to the level of safety improvement.

A CBA is one method that would either permit safety improvements to be directly compared against one another or be used as a tool to justify the funding investment to reduce the risk, but such an approach requires that a value be placed on preventing a fatality. This chapter will consider such an approach and will start by explaining the concept of the Value of a Statistical Life (VSL). It will then discuss existing Treasury Board Policy which captures the VSL approach. Finally, it will consider the approach taken by the UK's Ministry of Defence, which requires that Duty Holders reduce risk to an ALARP level while using a CBA approach to justify the investment. Such an approach incorporates the VSL concept and is compliant with higher government policy in the UK.

## Value of a Statistical Life

As stated above, budgets are limited, and taking a quantitative approach in reducing mortality risk ensures transparency, while focusing limited resources to achieve tangible outcomes that improve safety. Generating a CBA using a VSL allows for governments to apply a quantitative and transparent approach. Prior to discussing Treasury Board Policy on CBAs and how this could be applied to the military, it is

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[56] Canadian Broadcast Corporation, "Jury Finds Three Roof Deaths Were Preventable," last accessed 24 January 2023, https://www.cbc.ca/news/canada/windsor/jury-finds-three-roof-deaths-were-preventable-1.5094381.

necessary to explain the VSL concept. One way to consider the VSL concept is to consider the trade-off that people are willing to make between money and risk exposure. That is, the amount that someone is willing to be paid to accept a marginal increase in risk. If a large enough population is exposed to the increase in risk, then it eventually reaches a point in which a fatality, on average, would occur within that population. The cumulative amount that the population was willing to be paid to prevent one death is the VSL.[57] For example, consider two individuals doing the same job, but for different companies. The only thing different between the two jobs is their respective levels of safety. The individual working at Company A is paid $900 more per year than the person at Company B, but they are exposed to 1 in 10,000 chances of death due to a poor safety record at Company A. The person at Company B is completely safe, but they are paid $900 per year less than the person at Company A. If 10,000 people were employed at Company A, then on average there would be one death per year. If 10,000 people also worked at Company B, and each are willing to sacrifice (or pay) $900 per year to avoid this risk of death, then the resulting VSL is (10,000 people)($900/person) = $9 million.[58] It can therefore be stated that the value that society places on a statistical life is $9 million dollars in this example, but this concept can be taken further given large data sets and studies that are supported with industry wide questionnaires on risk preferences. Such an approach is known as the Hedonic Wage Methodology.

**Hedonic Wage Methodology**

The above example is an oversimplification to describe the risk versus reward trade-off concept that was noticed as far back as 1776 by the philosopher and economic theorist Adam Smith.[59] Today the process is more complex and uses an empirical approach to calculate the trade-off that people are willing to make, between risk and monetary gain, within the labor market. The most common method used today is known as the Hedonic Wage Methodology where several aspects of the job are controlled allowing the determination of the wage that workers receive for their risk exposure. The methodology also allows for companies to determine the investments required to improve safety, thereby lowering risk, and reducing the compensation they need to pay to employees. Similarly, because investments in safety initiatives are costly, firms with poor safety ratings will need to pay people slightly higher salaries, all else being equal, to offset the risk.[60]

The Hedonic Wage Methodology provides estimates based on industry-wide data, and when combined with micro-data sets, that is, questionnaires to an individual worker to evaluate each worker's risk and reward preference, a more accurate assessment of the

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57 W. Kip Viscusi, "Economic Lessons for COVID-19 Pandemic Policies," *Southern Economic Journal* 87, no. 4 (2021), 1067.
58 Melese, *Military Cost-Benefit Analysis: Theory & Practice*, 238
59 W. K. Viscusi, "The Value of Risks to Life and Health," *Journal of Economic Literature* 31, no. 4 (1993), 1913.
60 Viscusi, "The Value of Risks to Life and Health," , 1915

VSL can be produced.[61] A leading expert in the field states that, "labor market estimates of VSL serve as the principle basis for the valuation of mortality risks from a broad range of regulations, such as environmental and transportation regulations."[62]

There can be a wide range of VSL estimates for the United States from as low as $5 million USD ($4 million in 2015) to $12 million USD ($10 million in 2015)[63] with the US Department of Transport (DOT) using a figure close to $10 million USD ($8 million in 2015).[64] Continued refinement of the models, including the consideration of publication bias effects, has shown the figure in the US to be closer to $11 million USD for government policy makers.[65] A recent study by the same author on the Economic Impacts of the COVID-19 Pandemic, using labor market data, sights a VSL of $12.8 million USD ($11 million in 2018)[66] corrected for inflation.[67]

The above listed VSL figures, using the Hedonic Wage Methodology, are determined using labor market estimates to determine the wage-risk trade-off that people are willing to make. However, another commonly used method for determining a VSL, the Willingness to Pay Methodology, is worthy of further review as it is captured within Treasury Board Policy.

**Willingness to Pay Methodology**

An alternate method for calculating the VSL of a population, is referred to as the Willingness to Pay (WTP) methodology. The WTP method takes the same fundamental approach as described above under the Value of Statistical Life section, that is, it determines the amount that someone is willing to pay for a small reduction in risk of death. However, in this case the WTP method relies on stated preference surveys to estimate the VSL. For example, a researcher would create a questionnaire which would be sent out to a sample of the population to determine risk preferences aimed to understand how much an individual is willing to pay to reduce their risk of death due to heart attack versus cancer. A sample question from the study that is referred to within the Treasury Board policy is shown in Figure 3.1 as an example.

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[61] Viscusi, "The Value of Risks to Life and Health," , 1916
[62] W. Kip Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," *Journal of Benefit-Cost Analysis* 9, no. 2 (2018), 206.
[63] Cumulative inflation rate calculated to be 23.5% using https://www.usinflationcalculator.com/, last accessed 24 January 2023.
[64] Melese, *Military Cost-Benefit Analysis: Theory & Practice*, 239
[65] Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," , 228
[66] Cumulative inflation rate calculated to be 16.5% using https://www.usinflationcalculator.com/, last accessed 24 January 2023.
[67] Viscusi, "Economic Lessons for COVID-19 Pandemic Policies," , 1067

**If you had to choose, would you prefer Alternative A or Alternative B?**

| | **Alternative A** Constant annual risk reduction | **Alternative B** Constant annual risk reduction |
|---|---|---|
| Reduced risk for fatal | Heart attack | Cancer |
| Risk reduction each year: | reduced each year by: | reduced each year by: |
| For the next 10 years | 1 in 10,000 | 2 in 10,000 |
| 11 years from now and onward | 1 in 10,000 | 2 in 10,000 |
| Your current risks | Click here to view Table 1 | |
| Additional costs you pay each year starting now | $100 | $300 |
| **Which do you prefer?** | A ☐ | B ☐ |

**Figure 3.1 – Example of Willingness to Pay Survey Question**

Source: Chestnut, "Economic Valuation of Mortality-Risk Reduction: Stated Preference Estimates from the United States and Canada," 401.

The WTP method is more appropriate for determining a VSL based on health risks such as cancer, heart attacks, and food related illnesses, whereas the Hedonic Wage Methodology would be more appropriate for deaths caused by accidents.[68] This is simply due to the fact that people do not chose an illness, it is an unfortunate life event, and therefor stated preference surveys used in the WTP method are the only way to determine how much someone is willing to pay to reduce their risk. Conversely, the Hedonic Wage Method relies on vast datasets within industry, which provides an insight into what people are compensated for in higher risk jobs, which is then backed up by questionnaires. For workplace risks, such as inherent work-related risks within the CAF, the Hedonic Wage Methodology is therefore more appropriate to apply when determining a VSL.

There also appears to be discrepancy in literature for VSL estimates using questionnaires for both illnesses and accidents. It could be argued that if an individual was faced with a choice to reduce their risk of death in an accident by 1 in 10,000 versus reducing their risk of death of cancer by the same amount, that the value might be different. The difference between cancer related deaths and other causes of death has been noted, with the general population willing to pay more to reduce their risk of death

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[68] Lauraine G. Chestnut, Robert D. Rowe and William S. Breffle, "Economic Valuation of Mortality-Risk Reduction: Stated Preference Estimates from the United States and Canada," *Contemporary Economic Policy* 30, no. 3 (2012), 399.

of cancer. One study noted that the population they surveyed was willing to pay up to three times higher to prevent a death related to cancer than a death related to a vehicle accident.[69] The theory behind the data suggesting that people are willing to pay more to reduce their risk of a health-related terminal illness such as cancer is due to the prolonged pain and suffering. As discussed below, this is an important consideration when applying the most appropriate VSL, as underpinning assumptions used to get the figure need to be understood in order to apply an appropriate VSL to a given situation.

Having defined two fundamental approaches to estimating a VSL, that is Hedonic Wage and WTP, a review of Treasury Board policy can be conducted to examine the stated VSL, and more importantly the assumptions that underpin the VSL data. This is a necessary step in determining whether Treasury Board policy can be applied directly to the CAF, or if adjustments need to be accounted for based on assumptions in the data.

**Treasury Board Policy**

*Canada's Cost-Benefit Analysis Guide for Regulatory Proposals*,[70] captures the use of a VSL for producing CBAs. In other words, it allows for a value to be placed on preventing a fatality for industries to allocate resources accordingly to prevent fatalities. It should be noted that the intent of the guide is to provide standardization on the creation of CBAs to meet the higher-level Cabinet Directive on Regulation.[71] The directive states that CBAs are a requirement for federal regulatory proposals in order to fully capture all costs and benefits with emerging regulation to better qualify decisions. When applied to health and safety, regulations are expected to reduce risk and as such, the guide therefor provides a VSL figure to standardize the benefits of proposed regulation across departments. However, the guide does not fully explain the assumptions and instead provides the user with flexibility stating that a, "[CBA] may draw from existing VSLs that have been estimated using well-established methods."[72] The guide goes on to say that based on a study funded by Health Canada, that Canada's VSL is $6.5 million CAD

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[69] Chestnut, "Economic Valuation of Mortality-Risk Reduction: Stated Preference Estimates from the United States and Canada," , 400,

[70] Government of Canada, *Canada's Cost-Benefit Analysis Guide for Regulatory Proposals*, last accessed 15 November 2022, https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cost-benefit-analysis-guide-regulatory-proposals.html.

[71] Government of Canada, "Cabinet Directive on Regulation," last accessed 18 Nov 2022, https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cabinet-directive-regulation.html.

[72] Government of Canada, "Canada's Cost-Benefit Analysis Guide for Regulatory Proposals," last accessed 15 November 2022, https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cost-benefit-analysis-guide-regulatory-proposals.html.

in 2007 dollars,[73] equating to $8.9 million CAD in 2022 dollars[74] which Departments of the government are expected to use in the absence of other preferred and justified methods.

The specific study[75] sighted in the guide uses a WTP methodology to determine the above VSLs. Further review of the study indicates that stated preference surveys were used to assess the population's willingness to pay to reduce their risk of cancer and heart attack related deaths. As noted above, using a WTP methodology for terminal illnesses such as cancer is not the most appropriate when considering accidents in the workplace, including deaths related to military equipment shortfalls, as these deaths are immediate compared to those related to a terminal illness.

It is therefore proposed that the VSL provided in the guide may not be the most appropriate to apply in the case of military equipment, and a VSL based on either the Hedonic Wage Methodology or WTP method, that is not underpinned by cancer data, would be more appropriate.

**Proposed VSL for Military Equipment**

In a recent article[76] a leading expert in the area of establishing VSLs has stated that US government policy makers should be using an amount close to $13.6 million USD[77] ($11.4 million in 2017)[78] based on large data sets from the Census of Fatal Occupational Injuries (CFOI)[79]. The CFOI data set is a complete record of worker fatalities in the US that is validated by the Bureau of Labor Statistics (BLS) to the death certificate level and the coroners' report.[80] This allows fatality rates to be determined down to the occupation level, or by gender, race or age for example. When multiple years of CFOI data are compiled and combined with labor market data, as discussed in the Hedonic Wage Method section above, it is possible to refine risk preferences to a much more granular level.[81] Conversely, such a large data set also helps to reduce error

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[73] Government of Canada, "Canada's Cost-Benefit Analysis Guide for Regulatory Proposals," last accessed 15 November 2022, https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cost-benefit-analysis-guide-regulatory-proposals.html.
[74] Cumulative inflation rate calculated to be 36.7% using https://www.bankofcanada.ca/rates/related/inflation-calculator/, last accessed 24 January 2023.
[75] Chestnut, "Economic Valuation of Mortality-Risk Reduction: Stated Preference Estimates from the United States and Canada," , 399-416
[76] Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," , 205-246
[77] Cumulative inflation rate from 2017 to 2022 calculated to be 19.4% using https://www.usinflationcalculator.com/, last accessed 24 January 2023.
[78] Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," , 205
[79] This figure from Viscusi was published in 2017 and needs to be adjusted for inflation. In 2022 dollars this equates to $13.9 million USD, using www.usinflationcalculator.com.
[80] W. Kip Viscusi, *The Role of Publication Selection Bias in Estimates of the Value of a Statistical Life* (Cambridge: National Bureau of Economic Research, Inc,[2014]).
[81] Viscusi, *The Role of Publication Selection Bias in Estimates of the Value of a Statistical Life*

in VSL estimates due to the vast amount of data, thereby lending additional credibility to the $13.6 million USD VSL.

The research also used meta-regression analysis to account for publication bias effects across 68 individual studies that included 1025 VSL estimates.[82] It reports that a figure of $9.7 million USD ($8.1 million in 2017)[83] is most appropriate when using data from all studies, and an amount of $13.6 million USD when considering the US CFOI data.[84] The CFOI VSL is most appropriate given the robustness of the data, the analysis of each individual death by the BLS, and the fact that this data has little to no publication biases.[85]

Building on this work, in a study that considers the economic impacts of the COVID-19 pandemic,[86] the VSLs of multiple countries are calculated by using the US VSL result of $13.6 million USD as a baseline and then making an adjustment for differences in income between the two countries using GNI per capita, and "an income elasticity of the VSL of 1.0 based on evidence in meta-analyses of revealed preference studies."[87] The author makes clear that there may be differences in risk preferences between the two countries, but using an income adjustment is broadly seen as an acceptable method. Furthermore, regarding risk preferences between Canada and the United States, research has shown that US and Canadian VSL results are very close, with one study stating the following:

> None of the differences are statistically significant after adjusting for currency differences…it is reasonable to take into account results from US studies adjusted for currency differences, in Canadian policy analyses given the limited number of Canadian studies available.[88]

Given the limited number of studies in Canada, the US VSL can be used as a baseline and then a correction for GNI differences between Canada ($48,310)[89] and the US ($70,430).[90] This would yield the following VSL for Canada:

VSL = ($13.6M)*($48,310)/($70,430) = $9.32 million USD

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[82] Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," 210
[83] Cumulative inflation rate calculated to be 19.4% using https://www.usinflationcalculator.com/, last accessed 24 January 2023.
[84] Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," 228
[85] Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," 228
[86] Viscusi, "Economic Lessons for COVID-19 Pandemic Policies," , 1064-1089
[87] Viscusi, "Economic Lessons for COVID-19 Pandemic Policies," , 1068
[88] CHESTNUT, "Economic Valuation of Mortality-Risk Reduction: Stated Preference Estimates from the United States and Canada," , 413
[89] GNI per capita, Atlas method (current US$), The World Bank, last accessed 29 Nov 2022, https://data.worldbank.org/indicator/NY.GNP.PCAP.CD?most_recent_value_desc=true.
[90] GNI per capita, Atlas method (current US$), The World Bank, last accessed 29 Nov 2022, https://data.worldbank.org/indicator/NY.GNP.PCAP.CD?most_recent_value_desc=true.

Applying a conversion to Canadian dollars yields a VSL of $12.2 million CAD.[91] As stated above, Treasury Board policy states that, "[CBA] may draw from existing VSLs that have been estimated using well-established methods."[92] The $12.2 million CAD VSL is underpinned by industry accident data rather than health related data, and is therefore more appropriate to use than $8.9 million CAD, stated directly in Treasury Board policy. Therefore, $12.2 million CAD is the VSL that should be applied to CBAs for safety upgrades to military equipment.

Now that a CAF VSL is established, it is useful to compare how one of the CAF's closest allies, the United Kingdom (UK) military, determines whether military equipment upgrades are worth funding and what VSL they apply to their CBA process.

**United Kingdom Ministry of Defence**

The UK Ministry of Defence (MOD) is compliant with higher level government policy when it comes to the management of risk to life. The guiding document for all industries in the UK on how to comply with the Health and Safety at Work Act 1974 is titled, *Reducing Risks, Protecting People (R2P2)*, published by the Health and Safety Executive (HSE).[93] The document highlights that, "the public is… aware that, given few activities are without any risk, there must be a balance between the health and safety measures introduced to eliminate or control risks, and the costs arising or benefits forgone when the measures are introduced."[94] The role of risk assessments are explained along with the decision making process to ensure that controls are put in place to reduce risk to life by all managers who have a duty of care for those under their reporting chain.

The concept of risk being reduced to an ALARP level is a fundamental concept that is captured within R2P2. For a risk to be ALARP, it presumes that managers will implement measures to reduce risk until any further risk reduction measure is, "grossly disproportionate," to the benefit that it would bring.[95] The process leans towards safety as it places the burden on the manager to then justify why additional resources are not spent to further reduce risk. A CBA is one method to help justify whether further investment is either worthwhile, or grossly disproportionate to the benefit it brings, however the process is clear that a CBA cannot be used in isolation as risk management also requires judgement. Best practice can often be used to inform managers when

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[91] Using the Bank of Canada exchange rate one year average for 2022 of 1 CAD = 0.7662 USD, using www.bankofcanada.ca/rates/exchange/currency-converter, last accessed 24 January 2023.
[92] Government of Canada, "Canada's Cost-Benefit Analysis Guide for Regulatory Proposals," last accessed 15 November 2022, https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cost-benefit-analysis-guide-regulatory-proposals.html.
[93] United Kingdom, *Reducing Risks, Protecting People*, Health and Safety Executive Decision-Making Process, last accessed 29 November 22, https://www.hse.gov.uk/managing/theory/r2p2.pdf.
[94] United Kingdom, Health and Safety Executive Decision-Making Process, *Reducing Risks, Protecting People*, last accessed 29 November 22, https://www.hse.gov.uk/managing/theory/r2p2.pdf, v.
[95] ALARP "at a glance", Health and Safety Executive, last accessed 29 November 22, https://www.hse.gov.uk/managing/theory/alarpglance.htm.

applying judgement to justify the ALARP argument, and importantly, what grossly disproportionate factors should be used.

The disproportionate factor referred to above is simply the quantitative measure applied to a given activity and is proportionate to the risk. The risk can be determined to be ALARP if the condition in Figure 3.2 below are met:

$$\frac{\text{Costs}}{\text{Benefits}} > 1 \times DF$$

**Figure 3.2 – ALARP Grossly Disproportionate Equation from R2P2**

Source: Reducing Risks, Protecting People, Health and Safety Executive, "Cost-Benefit Analysis Checklist," last accessed 1 February 2023.

Where DF is the disproportionate factor. There is no specific guidance on what an appropriate DF should be for a given activity, but factors anywhere from 1 to 10 are applied based on previous best practice and comparable situations within the industry, such as within the UK MOD for example.[96]

Regarding CBAs, R2P2 states that, "where the benefit is the prevention of death, the current convention used by HSE, when conducting a CBA is to adopt a benchmark value of £1 000 000 (value stated in GBP in 2001) for the value of preventing a fatality (VPF)."[97] R2P2 explains that the method used to arrive at the £1 million is based on the WTP method described above, that is, in 2001, UK citizens were willing to pay £10 for a reduction in risk of death of one in a hundred thousand. It also goes on to explain that people are willing to pay significantly more for death related to cancer and therefore an adjustment is required for VPF related to hazards that could lead to cancer.

Turning to the UK MOD application of ALARP, specifically aviation risks across all MOD Elements, Regulatory Article 1210[98] captures the responsibility that senior officers have for the management of Risk to Life of the people under their command. The document provides guidance to ensure that risks are both ALARP and Tolerable, and more importantly describes guidance based on good practice as well as first principles to help senior officers identify, document, and mitigate risks to the appropriate level. Regulatory Article 1210 also refers to the Health and Safety Executive guidance

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[96] United Kingdom, Health and Safety Executive*, Principles and Guidance to Assist HSE in its Judgement That Duty-Holders Have Reduced Risk As Low As Reasonably Practicable*, last accessed 29 November 22, https://www.hse.gov.uk/managing/theory/alarp1.htm.

[97] Reducing Risks, Protecting People, Health and Safety Executive Decision-Making Process, last accessed 29 November 22, https://www.hse.gov.uk/managing/theory/r2p2.pdf, 73.

[98] United Kingdom, Ministry of Defence, *RA 1210 – Ownership and Management of Operating Risk (Risk to Life)*, last accessed 29 November 2022. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1108245/RA1210_Issue_6.pdf.

extensively and states that quantitative assessments, "will normally be based upon a CBA and a gross disproportionate test, the results of which will be used as evidence to support the ALARP claim." The VPF amount is not noted in the Regulation, and instead R2P2 is referenced, therefor £1.65 million (£1 million GBP in 2001)[99] is broadly applied when calculating the benefits of preventing a fatality in the UK MOD.

While the £1.65 million GBP VPF[100] appears to be significantly lower than the VSL published in the US ($13.6 million USD), or the Canadian VSL proposed above ($12.2 million CAD) from a CBA perspective, the UK approach still yields similar results due to the application of the disproportionate factor. Consider a case where the UK MoD is preparing a CBA to help determine if they should invest in a new light armored vehicle for their infantry. A disproportionate factor could range anywhere from 1 to 10, but a figure of 5 will be used in this example, noting that society has some tolerance for the military taking risk. A threshold investment value can then be determined by applying the equation in Figure 3.2:

(5) (£1 million) = £5 million GBP.

Adjusted for inflation[101] this equates to £8.3 million GBP and using an average exchange rate £0.6245 GBP to $1CAD for the average of 2022,[102] this works out to $13.3 million CAD as a threshold investment amount of one life being saved by the new light armored vehicles. The orders of magnitude are similar, $13.3 million CAD using the UK MOD method versus $12.2 million CAD using the proposed method in this paper; therefore, the two methods provide an interesting and supporting comparison of public opinion regarding how funds should be allocated to reduce risk. It should also be noted that the amounts above cannot be used in isolation, and that sensitivity studies would be required, along with a fully documented qualitative analysis.

With an appropriate VSL calculated, the CBA approach can then be applied to projects within the CAF. The final section of this chapter will consider how the CAF could adopt a CBA within existing process and policy, both from an in-service emergent risk perspective, and for new procurements.

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[99] Inflation average of 2.4% per year from 2001 to 2022 using the Bank of England inflation calculator, last accessed 24 Janurary 2023, https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator.

[100] Approximately equal to $2.64 million CAD using the bank of Canada Currency Converter, last accessed 24 January 2023, https://www.bankofcanada.ca/rates/exchange/currency-converter.

[101] Inflation average of 2.4% per year from 2001 to 2022 using the Bank of England inflation calculator, last accessed 24 Janurary 2023, https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator.

[102] Using the Bank of Canada Currency Converter, last accessed 24 January 2023, https://www.bankofcanada.ca/rates/exchange/currency-converter.

**Adopting a CBA within the CAF**

As discussed in Chapter 1, in-service risks have an existing process where they are managed through a combination of mitigation, and risk acceptance by the appropriate authority. Broadly speaking, these materiel risks are being shared by each of the Level Ones and ADM(Mat), but they are generally managed internally within ADM(Mat). In addition, C Prog staff have visibility on risks that are significant, along with guidance to help ensure risks are articulated up the chain of command so that appropriate resources can be allocated. It is not clear how effective this process is, noting the author's experience working in ADM(Mat),[103] however the policy is clear that C Prog staff have a mandate and are engaged to address significant risks that are raised by each of the Level Ones. While C Prog staff may have the ability to apply additional resources for the most significant risks, many other risks remain within each of the ADM(Mat) equipment leads, sometimes with insufficient resources to fully address them.

Consideration should therefore be given to further mature the existing link between ADM(Mat) equipment leads and C Prog staff, with a funding stream dedicated to safety improvements of military equipment. These safety improvements would need to be fully justified through the appropriate risk assessment, using the processes already described above in Chapter 2, along with a CBA that justifies the investment in funding. The CBA would include both a qualitative approach using sound principles of judgement and risk management to justify an ALARP position, as well as a quantitative approach to justify the risk is ALARP using a CBA and the VSL contained within this chapter. A threshold investment figure should be based on the following equation, with no requirement to include a Disproportionate Factor as applied by the UK.[104]

$$\frac{Cost}{Benefits} > 1$$

Equation 3.1 – Threshold ALARP Figure for BCAs

Where the Cost is the total investment required to lower the risk, and the Benefits account for the improved safety of personnel by considering lives saved using the VSL figure in this paper. Such an approach would also include a sensitivity analysis to prove the figures and process are robust. The above approach focusses primarily on in-service risks, that is, for risks that are uncovered after equipment enters service, however a similar approach should also be considered for the procurement of new equipment within DND. This can be accomplished through relatively straight forward changes to the existing procurement process.

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[103] The author was posted to ADM(Mat) from 2011 to 2014 to the Department of Technical Airworthiness and Engineering Support, and again from 2018 to 2020 as the CP140 Aircraft Engineering Officer.

[104] As discussed above, the UK apply Disproportionate Factors ranging from 1 to 10, however their VPF figure is significantly lower than the proposed VSL in this paper.

For new procurements, the *Project Approval Directive* (PAD),[105] is the guiding document that establishes the expectations for leaders and managers to bring in new capabilities into the CAF. It provides a step-by-step guide and can be applied to projects of varying size and complexity within DND.[106]

The PAD does not explicitly drive the user to fully evaluate the safety of the equipment being procured, however it does state the requirement to capture Constraints and Assumptions, which includes the Standards that need to be applied to the procurement project. This includes the compliance with health and safety standards as well as airworthiness standards for aircraft,[107] therefor minimum safety standards will apply during all procurement initiatives. However, direction is not provided on how safety should be evaluated if one option is safer than another, nor how the Project Team determine if additional investment should be made to further improve safety over and above the baseline design.

In addition, the PAD also captures the need to identify benefits that add value to the operation. The benefits need to be measurable improvements to DND's objectives and strategic priorities that are used as an input to the Business Case Analysis.[108] The objective the Business Case Analysis is to link the, "proposed investments with program results and, ultimately, with the strategic outcomes of DND."[109] This is started within in the Identification (ID) Phase of the project as shown in Figure 3.3 below.

[105] Department of Defence, Project Approval Directive, last modified 16 August 2019 (Ottawa: DND Canada, 2019).
[106] Department of Defence, Project Approval Directive, last modified 16 August 2019 (Ottawa: DND Canada, 2019), 22.
[107] Department of Defence, Project Approval Directive, last modified 16 August 2019 (Ottawa: DND Canada, 2019), 158.
[108] Department of Defence, Project Approval Directive, last modified 16 August 2019 (Ottawa: DND Canada, 2019), 31.
[109] Department of Defence, Project Approval Directive, last modified 16 August 2019 (Ottawa: DND Canada, 2019), 80.

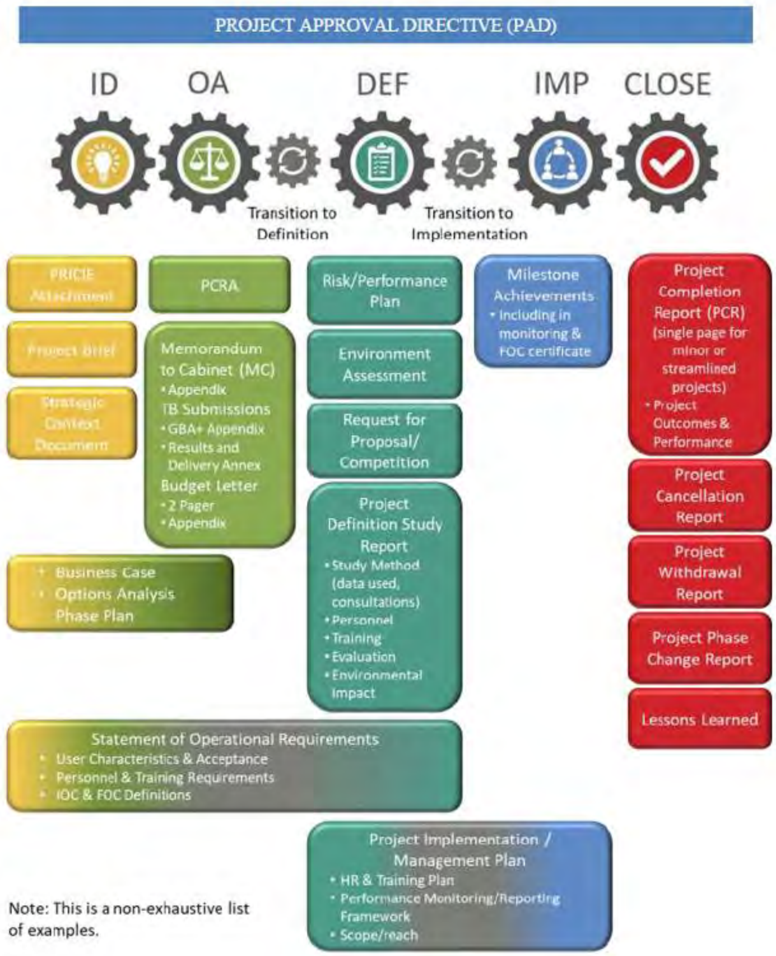


**Figure 3.3 – PAD Overview Showing Business Case and PRICIEG Deliverables**

Source: Department of Defence, Project Approval Directive, last modified 16 August 2019 (Ottawa: DND Canada, 2019), 204.

The Business Case Analysis includes a CBA section as well, along with a template that guides the user through high level criteria such as Value for Money and Flexibility.[110] Economic benefits are captured at the end of the template with Cost-effectiveness and avoided costs. In other words, this last section allows the Project Team to justify that the investment outweighs the cost, or if the system replaces another system, the Project Team can justify the new equipment is worth it based on a least-cost basis, which is in line with Equation 3.1 above. The only downfall is that the PAD, nor

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[110] Included in Annex E of this paper for ease of reference

supporting annexes, does not explicitly mention safety improvements to equipment as an input to the CBA.

Also, within the PAD, and supporting the Business Case Analysis, is the PRICIEG Annex which is a list of special considerations to help the Project Team in assessing the project against various factors that are critical to defence. Some examples include personnel, research and development, infrastructure and environment, concepts and doctrine, equipment, support and sustainability and Gender-Based Analysis Plus. The personnel, equipment and GBA+ sections of the PRICIEG Annex, do not currently capture the need to consider safety considerations of equipment, and these are the areas in the Annex where safety should be captured. Like the Business Case Analysis, a preliminary PRICIEG Annex is submitted early in the project as shown in Figure 3.3 above.

There are two locations where safety requirements should be captured under the PAD. The first is within the Business Case Analysis under the CBA portion of the document. This section should provide guidance to Project Teams that economic safety benefits should be considered during the subsequent Options Analysis phase. While nothing prevents the user currently from doing this, economic safety benefits, as described in this paper, may not naturally be thought of but they could be a significant difference across the system options available. The second location where safety should be mentioned within the PAD is under the PRICIEG section, as stated previously. A paragraph stating that economic safety considerations should be considered along with guidance material, and a reference to *Canada's Cost-Benefit Analysis Guide*,[111] which includes VSL calculations as a viable input to CBAs as discussed earlier in this chapter, should be included in either the Personnel or Equipment sections of the document.

The above approach would not only improve safety of military personnel, but it would also provide a more objective process for the equitable distribution of limited resources within DND. A similar process has been applied within the UK and has proven effective, and it is now also being considered within the US military.

The final chapter will consider an example from the US military where a retrospective look was applied to a major investment in materiel to reduce the risk to soldiers overseas. The example applies a CBA to a major procurement initiative after the equipment was employed in theatre to evaluate whether the investment could be considered the best way to expend resources related to safety for the US military. Even though this paper advocates that a CBA should be completed in order to justify funding, or to prove an ALARP position, the following example demonstrates the advantage that

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[111] Government of Canada, "Canada's Cost-Benefit Analysis Guide for Regulatory Proposals," last accessed 15 November 2022, https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cost-benefit-analysis-guide-regulatory-proposals.html.

CBA can provide in a resource constrained environment, in an effort to maximize safety across defence.

# CHAPTER 4 - EXAMPLE OF COST-BENEFIT ANALYSIS

## Case study on the cost-effectiveness of armored vehicles

The Naval Postgraduate School in Monterey California published a study in 2012 on *The Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas US Army Operations*.[112] The study is worth noting because it reviewed the investment cost of different vehicles, each with increasing levels of protection, and then compared that with the lives lost across each of the units operating the vehicle types. The study therefore took a unique retrospective look at the investment that had already taken place and whether the investment was worth it in terms of lives saved, considering funding could potentially be used in other risk reduction areas. The units that were analyzed included Infantry Units, Armored and Cavalry Units, Administrative and Support Units, and Other Unit Types. While several assumptions were made in the study, and will be discussed below, the results provide insight into the potential benefits of using a CBA to justify safety upgrades to military equipment.

The study does not disclose the specific location where the data was gathered, but refers to the location as Theatre A during the Global War on Terror. It considers two large scale tactical wheeled vehicle replacement programs, the first was moving from a light Type 1 vehicle to a more heavily armored Type 2 vehicle at a cost of $170,000 USD per vehicle. The second replacement program moved from the Type 2 vehicle to a significantly more expensive, $600,000 USD Type 3 vehicle with a project cost of $35 billion USD.[113] The study covered a 71-month period and reviewed the number of vehicles that were introduced into each of the four-unit types over that period. The study then reviewed the number of hostile injuries, the number of deaths other than Killed in Action (KIA) as well as KIA for each unit. The cost per life saved could then be estimated for each of the units based on the casualties each month and the point at which each vehicle type was phased into each unit.

The change from Type 1 to Type 2 vehicles correlated to a reduction in fatality rate of 0.04-0.43 per month at a range of $1.1 million to $24.6 million USD per life saved.[114] Note, however that the high estimate of $24.6 million USD was obtained with relatively few control variables.[115] When fixed effects were added, the estimates are significantly lower and well below the target value of $9.1 million USD used in the study. In other words, the cost was justified moving from the Type 1 to the Type 2 vehicle when considering a VSL of $9.1 million USD. The implementation of the Type 3 vehicles was determined to not be cost effective with cost per life saved being well above

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[112] Chris Rohlfs and Ryan Sullivan, "The Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas Us Army Operations," *Defence and Peace Economics* 24, no. 4 (2013), 293-316.
[113] This figure captures the first three years of the project.
[114] Rohlfs, "The Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas Us Army Operations," , 294
[115] Rohlfs, "The Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas Us Army Operations," , 307

the target VSL in the study, but this could be due to several factors including assumptions made in the study as well as the change in combat environment and the point at which the Type 3 vehicles were introduced.

The study recognized the changes in combat environment that might skew the estimates in the study, the favorable conditions of the urban operating environment for Type 2 vehicles versus Type 3 vehicles, and the change in number of units that occurred throughout the 71-month period. Furthermore, changes in behavior by both the enemy and US Forces, that may have resulted over the 71 months was not accounted for due to the data driven focus of the study.

It should also be noted that a report[116] was also published sighting concerns with a lack of operational context in the original study. The report captures gaps that question the claim that the Type 3 vehicles were not cost effective. Data does in fact indicate that the Type 3 vehicle deliveries occurred around the same time that under vehicle IED attacks increased.[117] So while the Type 3 vehicles were introduced near the end of the war, "during a relatively calm period,"[118] the under vehicle IED attacks appear to have increased, while at the same time, deaths and injuries were on a decline according to the original study.[119] The report goes on to say that the Type 3 vehicles, "provide the best currently available protection against IEDs. Experience in theater shows that a Marine is four to five times less likely to be killed or injured in a [Type 3 vehicle] than in a [Type 2 vehicle]."[120]

Reviewing both reports indicates that the CBA approach helped to justify the investment of the Type 2 vehicles. However, additional data should be gathered that directly links the deaths to each vehicle type before the Type 3 vehicle could be discounted as a worthwhile investment. This helps justify the claim in this paper that a CBA is a valuable tool, but that a CBA alone should not be used in isolation as additional variables will inevitably feed into the evaluation of equipment safety improvements.

It should be noted that the author of the original study is currently gathering further evidence to clarify and to address the comments made on the critique article. It is also expected that the author will release additional findings and recommendations on the

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[116] Franz J. Gayl, "Incomplete Rohlfs-Sullivan Analysis of the Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas Us Army Operations," *Defence and Peace Economics* 24, no. 5 (2013), 465-484.

[117] Gayl, "Incomplete Rohlfs-Sullivan Analysis of the Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas Us Army Operations," , 472

[118] Rohlfs, "The Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas Us Army Operations," , 310

[119] Rohlfs, "The Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas Us Army Operations," , 301, Figure 3

[120] Gayl, "Incomplete Rohlfs-Sullivan Analysis of the Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas Us Army Operations," , 473

application of CBAs for the US military, including an appropriate VSL specifically for military personnel.[121]

[121] Ryan Sullivan, telephone conversation with author, 17 November 2022.

## CHAPTER 5 - CONCLUSION AND RECOMMENDATIONS

The CAF continues to be an organization that cares about the morale, welfare, and safety of its personnel. Broadly speaking, the members that serve the CAF feel supported by their chains of command, and certainly at the tactical level, commanders use all tools within their toolbox to ensure the safety of their personnel. Commanders care about their people as fellow human beings, and they also recognize that the people are their most valuable resource in being able to achieve their mission. This duty of care is not only something commanders embody, as almost anyone who has witnessed the speeches during a change of command ceremony can attest to, but it is captured formally within CAF doctrine as described in Chapter 2.[122,123]

However, commanders only have so many tools at their disposal to mitigate risk to their personnel, and they recognize that a balance between safety and skill development must be struck to allow them to continue to train and fulfil their mandate when called upon by the government of Canada. This paper explored some of the challenges that commanders face in securing the necessary resources to mitigate risk to their personnel. It was noted that risks can be identified using the established processes within each of the respective Elements, fed upwards through the chain of command, and if they reach a high enough level, then under the *Defence Enterprise Risk Management Policy*,[124] discussed in Chapter 2, C Prog staff may be able to address the issue under their resource planning and allocation process.[125] However, not all risks make it to this level, and it is therefore left up to commanders in the field, and ADM(Mat) personnel, to prioritize what the significant risks are, to articulate them, and attempt to secure the appropriate resources to address them. This is not always successful in a resource constrained environment with fluctuating budgets year over year.

It was also noted above how in-service materiel risks are captured within each of the Elements, and it is clear that a standardized process does not exist to manage risk within the CAF. The RCN have a mature process in place, but the process is ambiguous with guidance as to when further risk mitigation is no longer required. The concept of ALARP is indeed captured, but the guidance is not only subjective, it does not provide a tool for commanders, nor ADM(Mat) personnel, to advocate for resources to address risks they feel are critical to the safety of front-line personnel.

On the other hand, the RCAF risk management process has been in place for decades which has allowed it to mature significantly into a robust model that was then

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[122] Department of National Defence, B-GJ-005-314/FP-000, *CF Joint Force Protection*, (Ottawa: DND Canada, 2007).
[123] Department of National Defence, B-GJ-005-502/FP-000, *Risk Management of CF Operations*, (Ottawa: DND Canada, 2007).
[124] Department of Defence, Defence Enterprise Risk Management Policy, Chief of Programme, 26 July 2018.
[125] Department of Defence, Defence Enterprise Risk Management Policy, Chief of Programme, 26 July 2018, 2.

copied and adopted by the CA. Both models allow for risk to be defined using standard definitions of severity and probability, and then mitigated appropriately. Like the RCN process, personnel on the technical and operational side are identified as being able to accept residual risk depending on what level the residual risk resides. By virtue of capturing this risk formally, the risk acceptance authorities are at a high enough level that resources can sometimes be allocated from within existing budgets to eliminate the risk all together; sometimes with a materiel solution such as a modification. For example, the software redesign of flight deck cautions and warnings for the C-295 is a significant cost and is causing program delays,[126] however resources were allocated as the risk of operating the aircraft was not worth accepting. With the fatal Cyclone accident on 29 April 2020 being attributed to a software glitch,[127] it is easy to see why the software redesign of the C-295 was required, and appropriate resources allocated.

On the other hand, lesser risks are often difficult to justify in the face of competing budgets. As explained in this paper, in-service risks will fall within a matrix for each of the Element's risk management processes. The RCAF and CA have target thresholds to mitigate to ALOS and ALOR respectively. If above the threshold then a risk control plan is required, but that doesn't always mean sufficient funding will be allocated immediately, even if formally captured, as the residual risk may be accepted. Furthermore, while the RCAF and CA would argue mitigating to the ALOS and ALOR lines, respectively, are all that is needed, this appears to contradict CAF doctrine which does explore the concept of commanders making decisions based on the risk and resources available.[128] In other words, if a risk is below ALOS or ALOR line, but further mitigation has a minimal cost, then the resources should be allocated to further mitigate risk to personnel, using the ALARP concept.

Using a CBA to advocate for funding for safety related equipment or modifications is an objective way of demonstrating that the risk is ALARP. A CBA helps to demonstrate whether monetary investment in equipment is grossly disproportionate to the reduction in risk that the equipment provides. Such a process is also in-line with the spirit of existing CAF doctrine, risk management principles, and has also been adopted by one of our closest allies, the UK MOD. Fundamental to generating a CBA is allocating an appropriate value in preventing a fatality, or VSL.

This paper explored two broadly acceptable methods of determining a VSL and advocated that VSL figures should be based on the trade-off that people are willing to make between risk and monetary gain within the labor market, as this is most appropriate when applied to the military. Treasury Board policy captures the use of CBAs, but the VSL that they provide, $8.9 million CAD, is based on a WTP method for health-related

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[126] David Pugliese Ottawa Citizen, "Technical Issues Behind Delays Affecting Canada's New Search and Rescue Planes," *The Ottawa Citizen (Online)*2022.

[127] "Software Glitch Contributed to Fatal Naval Helicopter Crash that Killed Six." *National Post (Online)*2021.

[128] Department of National Defence, B-GJ-005-314/FP-000, *CF Joint Force Protection*, (Ottawa: DND Canada, 2007), 2-4.

illnesses. The policy does permit the use of more appropriate VSL figures provided they are backed up by research. This paper therefore proposes a VSL of $12.2 million CAD supported by academic research on VSL estimates using large labor market data sets in the US, and then adjusted for differences between Canadian and US GNI, and exchange rates.

It should be noted that references in this paper stated that VSLs using a WTP method can generate higher VSLs than that based on labor market data due to people's higher aversion to death due to a painful terminal illness such as cancer. [129] Emerging research at the Navy Post Graduate School[130] as well as the latest studies referenced in this paper[131,132] actually found higher VSL estimates using labor market data ($12.2 million CAD in 2022 dollars) than Canadian Treasury Board VSLs ($8.9 million CAD in 2022 dollars) which were underpinned by WTP data based on cancer deaths. It is not known why this discrepancy exists, but it is important to note as further investigation could be conducted to understand the reason. For the purposes of this paper, it was deemed most appropriate to use the labor market data, with a conversion using Canada's GNI and exchange rate, for the military context. This is simply because military equipment upgrades should be based on labor market risks, as that is what personnel are primarily exposed to in the military context rather than risks due to terminal illnesses.

Commanding officers in each of the Elements, and key personnel within ADM(Mat) responsible for safety of equipment, should be permitted to use CBAs as a method to help justify investments in safety upgrades. While nothing prevents their use in existing policy, their application should be given significant weight, and if the investment is not grossly disproportionate to the level of safety improvement, then funding should be allocated accordingly. If the CBA and corresponding ALARP argument support the investment, then there should be an obligation to mitigate the risk and fund the initiative. A challenge will be where does the funding come from.

One avenue is to further mature the process within C Prog, under the *Defence Enterprise Risk Management Policy*, and continue to improve the communication with Weapon System Managers within ADM(Mat) to establish an appropriate funding stream and process that can be quickly accessed. Another option exists to establish a safety specific budget under ADM(Mat) so that equipment purchases or modifications do not compete with in-service capability improvements. Senior managers have visibility on the highest risks to materiel, however when risks are managed at a lower level, the line between operations and safety can become blurred. Continuing to mature the process with C Prog, or establishing a safety specific budget line, that can be tapped into using

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[129] CHESTNUT, "Economic Valuation of Mortality-Risk Reduction: Stated Preference Estimates from the United States and Canada," , 399

[130] Ryan Sullivan, telephone conversation with author, 17 November 2022.

[131] Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," , 205-246

[132] Viscusi, "Best Estimate Selection Bias in the Value of a Statistical Life," , 205-246; Viscusi, "Economic Lessons for COVID-19 Pandemic Policies," , 1064-1089

CBAs, would assist ADM(Mat) personnel to enhance safety, and support Commanding Officers in the field by helping to reduce risk to their personnel.

A number of recommendations are made based on the research conducted during this paper. Some of the recommendations are aimed at the overall objective of this paper, which is to advocate the use for CBAs for safety related improvements to military equipment. Other recommendations though, are aimed at further maturing the risk management process within the CAF, as some inconsistencies were noted during the research. The later will be captured first.

**Recommendation One - ALARP Concept**

Mitigating risk to the level of ALARP should be a requirement within each of the Element's risk management processes. It is recommended that the concept of ALARP be better defined within each of the Element's materiel risk management processes, and most importantly, it should be stated that key ADM(Mat) personnel, such as the technical equipment leads for each of the platforms, have a responsibility to ensure that materiel risk is ALARP. The RCN have captured the concept, but do not expand on how it can actually be applied and leveraged. This should be explained, including guidance on how to determine the point at which further risk mitigation is no longer required.

The ALARP concept should be explained within RCAF Risk Management Process. The concept is captured in the *Airworthiness Risk Management Course*, stated as, As Safe As Reasonably Practicable (ASARP) but it is only listed on a single slide during the course,[133] and not captured or explained elsewhere within policy.

The ALARP concept should also be further defined within the *DGLEPM System Safety Program*. At the time of writing this paper, the concept was not captured within the DGLEPM process, which is understandable given it is based on the RCAF's system.

**Recommendation Two - Use of CBAs to Justify Safety Improvements of Military Equipment**

The use of CBAs should be referenced formally in policy to help justify safety upgrades to military equipment. They should be used as a supporting tool, but not the only method for determining whether a safety investment is worthwhile. When included, they should also include a sensitivity analysis as part of the justification which helps prove the process is robust.

While policy does not explicitly prohibit their use, under existing resource constraints, funding allocation may not change even if underpinned by a CBA that quantitatively justified the investment. The UK require that government departments

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[133] Department of Defence, *Airworthiness Risk Management Course*, slide 22 (Ottawa: DTAES, 24-25 September 2018).

apply ALARP principles and therefore the use of CBAs, in their analysis. This is captured under a government Act, and therefore must be complied with. If ALARP concepts and CBAs are not captured in CAF policy, then safety to personnel is very difficult to weigh when considering resource allocation, or, worst case, it gets neglected all together.

The use of CBAs should therefore be included within each of the Element's in-service risk management processes, to help support an ALARP argument.

Regarding initial acquisition of materiel, the CAF have captured CBAs within the PAD for procurement, however, guidance on the inclusion of safety improvements is not provided, nor a reference to ALARP concepts. The PAD should be amended to include guidance on economic safety benefits within the CBA portion of the document and it should provide guidance to the Project Teams to include economic safety benefits during the Options Analysis phase. In addition, the PAD's PRICEIEG Annex lists the special considerations to help the Project Teams assess various factors that are critical to defence, and a reference should be included to consider safety to personnel using an economic, CBA, approach. This should include references to *Canada's Cost-Benefit Analysis Guide*[134] for VSL figures, or a reference to this paper for an appropriate VSL.

**Recommendation Three - Value of Statistical Life**

It is recommended that the CAF use $12.2 million CAD for a VSL. While this diverges from Treasury Board policy, it still meets the intent, as allowance is provided for alternate VSL figures provided they are backed up by academic research, such as the justification provided in this paper.

**Recommendation Four - Further Research**

Additional research could be conducted to better understand why labor market data from the US yields a VSL that is higher than the WTP figure referenced in Treasury Board policy. This would help to understand why a WTP figure that is based on cancer related deaths is lower than labor market data, when the opposite was expected. In other words, it was expected that the labor market data would have yielded a lower VSL that the WTP figure which accounts for suffering from a terminal illness.

Further research could also be conducted on risk preferences within a Canadian context. This data was largely absent from the literature review, and while some evidence was found in academic articles, it focused on WTP processes based on terminal illness, and not risks in the labor market.

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[134] Government of Canada, "Canada's Cost-Benefit Analysis Guide for Regulatory Proposals," last accessed 15 November 2022, https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cost-benefit-analysis-guide-regulatory-proposals.html.

In addition, further research is suggested in understanding if VSL figures should be different for military personnel specifically. This paper advocated a VSL based on large data sets from US labor figures and then converted to a Canadian value using a GNI adjustment and USD to CAD exchange rates. Such an approach has been used in academia as described in this paper, however it could be argued that the military deserves special consideration. There are arguments on both sides. One could consider the fact that people that join the military are, broadly speaking more comfortable with risk, and as such will not demand to be paid a premium for the higher risk exposure, compared to other members of society. They also tend to be younger in general than a random subset of the population, and younger people tend to be more risk tolerant, requiring less compensation for risk exposure. This would have the effect of lowering the VSL for military personnel.

On the other hand, strictly from an economic perspective, some trades in the military are very expensive to train compared to other civilian professions. As such, it could be more appropriate to assign a higher VSL figure to military personnel as a whole, or even to select trades. These aspects deserve further consideration, and are worthy of a focused study to help better refine an appropriate VSL figure for the CAF when conducting CBAs.

## ANNEX A – CANADIAN ARMED FORCES MATERIEL ASSURANCE AUTHORITY TABLE

### Table A.1 - Authority Table for Materiel Assurance

| The... | has or have the authority to … |
|---|---|
| ADM(Mat) | • issue materiel assurance policies, instructions, directives and guidelines except in respect of materiel managed by Assistant Deputy Minister (Information Management) (ADM(IM)), Assistant Deputy Minister (Defence Research and Development Canada) (ADM(DRDC)) and Director General Health Services (DGHS); and<br>• establish cyber materiel assurance for platform technology managed by ADM(Mat). |
| Commanders of the RCN, CA, RCAF, CJOC and MPC | • issue materiel assurance policies, instructions, directives and guidelines, other than DAOD, to meet their operational objectives. |
| Commander CANSOFCOM | • issue materiel assurance policies, instructions, directives and guidelines, other than DAOD, to meet their operational objectives; and<br>• govern materiel assurance for materiel managed by CANSOFCOM. |
| ADM(IM) | • issue materiel assurance policies, instructions, directives and guidelines, other than DAOD, for the information management (IM) and information technology (IT)<br>• materiel managed by ADM(IM);<br>• govern materiel assurance for materiel managed by ADM(IM); and |

| | |
|---|---|
| | • audit the application of cyber materiel assurance when the platform technology managed by ADM(Mat), ADM(DRDC) and DGHS interfaces with IM and IT<br><br>• managed by ADM(IM). |
| ADM(DRDC) | • issue materiel assurance policies, instructions, directives and guidelines, other than DAOD, for materiel managed by ADM(DRDC); and<br><br>• govern materiel assurance for materiel managed by ADM(DRDC). |
| DGHS | • issue materiel assurance instructions, directives and guidelines, for medical materiel managed by DGHS; and<br><br>• govern materiel assurance for medical materiel. |
| Director General Maritime Equipment Program Management, Director General Land Equipment Program Management and Director General Aerospace Equipment Program Management | • issue materiel assurance instructions, directives and guidelines for materiel under their responsibility; and<br><br>• govern materiel assurance for materiel under their responsibility. |

Source:  Department of National Defence, *DAOD 3035-0, Material Assurance, Government of Canada, (Ottawa: DND Canada, 2021),* Section

# ANNEX B - AIRWORTHINESS RISK SEVERITIES AND PROBABILITIES

## Table B.1 – Airworthiness Risk Hazard Severity for Aircraft

| Description | Category | Definition |
|---|---|---|
| **Catastrophic** | A | For **manned aircraft**, hazard conditions that would prevent continued safe flight and landing including the potential loss of aircraft. For **unmanned aircraft**, hazard conditions that involve an uncontrolled crash of a Class II or III UAS.<br><br>These conditions could also result in the death or incapacitation of flight crew or multiple fatalities among aircraft occupants or people on the ground. |
| **Hazardous** | B | For **manned aircraft**, hazard conditions that would reasonably be expected to result in major damage to an aircraft system or a large reduction in safety margins or functional capabilities, including higher crew workload or physical distress such that crew may not be relied upon to perform tasks accurately or completely. For **unmanned aircraft**, hazard conditions that involve a controlled crash leading to the loss of a Class II or III UAS or an uncontrolled crash of a Class I Small UAS.<br><br>These conditions could also result in a single fatality or serious injuries[1] to aircraft occupants or people on the ground. |
| **Major** | C | For **manned aircraft**, hazard conditions that would reasonably be expected to result in minor damage to an aircraft system or moderate reduction in safety margins or functional capabilities, including a moderate increase in crew workload or physical distress impairing crew efficiency. For **unmanned aircraft**, hazard conditions that involve a controlled crash leading to the loss of a Class I Small UAS or an uncontrolled crash of a Class I Mini UAS.<br><br>These conditions could also result in physical distress to aircraft occupants or moderate injuries[2] to aircraft occupants or people on the ground. |
| **Minor** | D | For **manned aircraft**, hazard conditions that would not significantly reduce aircraft safety, but would reasonably be expected to result in a slight reduction in safety margins or functional capabilities, including a slight increase in crew workload. For **unmanned aircraft**, hazard conditions that involve a controlled crash leading to the loss of a Class 1 Mini UAS or an uncontrolled crash of a Class I Micro UAS.<br><br>These conditions could also result in minor injuries[3] to aircraft occupants or people on the ground. |
| **Negligible** | E | Hazard conditions that that have no effect on safety and negligible effect on safety margins. For **unmanned aircraft**, also involves a controlled crash of a Class 1 Micro UAS. |

*[1] A serious injury is any injury that requires hospitalization and causes the permanent loss of certain physical functions. Consequences of this injury may be life-threatening and irreversible.*

[2] *A moderate injury is any injury for which medical attention including hospitalization may be required or that could cause the temporary loss of certain physical functions. Consequences of this injury are not life-threatening and are reversible*

[3] *A minor injury is any injury for which no medical attention other than first-aid is necessary or that does not substantially hamper physical functioning.*

Source: Department of National Defence, *EMT01.003 Airworthiness Risk Management Process*, *(Ottawa: DND Canada, 2022),* Annex A-1

**Table B.2 – Airworthiness Risk Hazard Probability (Quantitative)**

| Description | Level | Hazard Probability Threshold (per flight hour) | | | |
|---|---|---|---|---|---|
| | | DND Passenger Carrying Aircraft *(Derived from FAR 25/29 Civil Designs)* | Military Aircraft | Military Aircraft (Equipped With Ejection Seat) | Unmanned Aircraft Systems (UASs) (above 150 kg TOW) |
| **Frequent** | **1** | Greater than $1 \times 10^{-3}$ | Greater than $1 \times 10^{-3}$ | Greater than $1 \times 10^{-3}$ | Greater than $1 \times 10^{-2}$ |
| **Probable** | **2** | Less than $1 \times 10^{-3}$ | Less than $1 \times 10^{-3}$ | Less than $1 \times 10^{-3}$ | Less than $1 \times 10^{-2}$ |
| **Remote** | **3** | Less than $1 \times 10^{-5}$ | Less than $1 \times 10^{-5}$ | Less than $1 \times 10^{-4}$ | Less than $1 \times 10^{-3}$ |
| **Extremely Remote** | **4** | Less than $1 \times 10^{-7}$ | Less than $1 \times 10^{-6}$ | Less than $1 \times 10^{-5}$ | Less than $1 \times 10^{-5}$ |
| **Extremely Improbable** | **5** | Less than $1 \times 10^{-9}$ | Less than $1 \times 10^{-8}$ | Less than $1 \times 10^{-7}$ | Less than $1 \times 10^{-6}$ |

Source: Department of National Defence, *EMT01.003 Airworthiness Risk Management Process*, *(Ottawa: DND Canada, 2022),* Annex A-2

**Table B.3 – Airworthiness Risk Hazard Probability (Qualitative)**

| Description | Level | Qualitative Definition | Life of Individual Aeronautical Product | Life of Entire Fleet | Individual Aircrew Career | All Exposed Personnel |
|---|---|---|---|---|---|---|
| **Frequent** | **1** | Likely to occur many times. | Expected to occur many times during the operational life of an individual aircraft | Occurs continuously to the entire fleet | Expected to occur many times during an individual's career | Occurs continuously to the entire population |
| **Probable** | **2** | Expected to occur one or more times | Expected to occur one or more times during the operational life of an individual aircraft | Likely to occur several times per year to the entire fleet | Expected to occur one or more times during an individual's career | Likely to occur one or more times per year to the aircrew population |
| **Remote** | **3** | Unlikely, but possible to occur | Unlikely, but possible to occur during the operational life of an individual aircraft | May occur one or more times per year to the entire fleet | Unlikely, but possible to occur during an individual's career | May occur one or more times per year to the aircrew population |
| **Extremely Remote** | **4** | Not expected to occur | Not expected to occur during the operational life of an individual aircraft | May occur one or more times during the entire operational life of the entire fleet | Not expected to occur during an individual's career | May occur one or more times to the entire aircrew population |
| **Extremely Improbable** | **5** | So unlikely, it may be assumed that it will never occur | So unlikely, it may be assumed that it will never occur during the entire operational life of all aircraft of the type | | | |

Source: Department of National Defence, *EMT01.003 Airworthiness Risk Management Process*, *(Ottawa: DND Canada, 2022),* Annex A-3

# ANNEX C – IN-SERVICE NAVAL MATERIEL RISK SEVERITIES, PROBABILITIES AND NOTES

## Table C.1 – Royal Canadian Navy Risk Severity Definitions

| | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| | | **Negligible** | **Marginal** | **Significant** | **Critical** | **Catastrophic** |
| Severity | **Mission** | Mission continues<br>Minor capability degradation | Mission element failure(s)<br>Mission continues with minor degredation | Single significant mission element failure<br>May be unsuitable to continue | Multiple significant mission element failures<br>Unsuitable to continue | Total mission failure<br>Inability to continue |
| | **Personnel** | Minor injuires treatable by First Aid | Single minor injury<br>Single temporary disability<br>Emergency medical treatment<br>Injury eligible for compensation | Single severe injury<br>Mulitiple minor injuries<br>Single permanent disability<br>Multiple temporary disabilities | Single death<br>Multiple severe injuries<br>Multiple permanent disablilites | Multiple deaths |
| | **Materiel** | Cosmetic damage Defect rectification<br>No impact on operations<br>1st line resources | Minor damage<br>Temporary loss of service/equipment<br>1st/2nd line resources | Major damage<br>Temporary loss<br>Specialist repair crew<br>2nd/3rd line resources | Severe damage<br>First Level system damage<br>Extended loss<br>Specialist repair crew<br>2nd/3rd line resources | Damaged beyond repair |

Source: Department of National Defence, *C-23-005-000/AG-002, Naval Materiel Risk Management (Ottawa: DND Canada, 2013),* A-2.

## Table C.2 – Royal Canadian Navy Risk Probability Definitions

| | | | Individual Item | Total CF Inventory | |
|---|---|---|---|---|---|
| Probability | 1 | **Improbable** | So unlikely it may not be experienced | Unlikely to occur, but possible | < 1/1000 yr |
| | 2 | **Remote** | Unlikely, but could possibly occur in the life of the item | Unlikely, but can be reasonably expected to occur in the inventory | 1/100 to 1/1000 yr |
| | 3 | **Occasional** | Unlikely, but can be reasonably expected to occur in the life of the item | Will occur several times in the inventory | 1/10 to 1/100 yr |
| | 4 | **Probable** | Will occur several times in the life of the item | Will occur regularly in the inventory | 1/yr to 1/10 yr |
| | 5 | **Frequent** | Likely to occur regularly | Continuously experienced in the inventory | > 1/yr |

Source: Department of National Defence, *C-23-005-000/AG-002, Naval Materiel Risk Management (Ottawa: DND Canada, 2013),* A-2.

### Notes from Table 2.4

Note 1: Technical Endorsement and Technical Approval Authority may be delegated to FTA in specific cases.

Note 2: Endorsement of Acceptable with Review risks that affect Certificates of Safety reside with the DA (C-23-005-000/AG-002 NMRM Page 3.4)

Note 3: For Ships Deployed on Named Operations, the authority to accept risks assessed as undesirable or intolerable rests with MCC(W), D/MCC or MCC as indicated. As operational transfer, the FE Commander is accepting all of the FG Commander's accepted risk.

Note 4: When a TG is deployed, the embarked CTG is the operational authority to accept risk assessed as undesirable for TG ships.

## ANNEX D – CANADIAN ARMY SEVARITIES AND PROBABILITIES

### Table D.1 – Land Hazard Severity Definitions

| Description | Category | Definition |
|---|---|---|
| **Catastrophic** | **A** | All hazard conditions which would prevent continued safe operation. Could result in death of the vehicle crew normally with loss of the land equipment. (*e.g. Medium Floating Bridge corrosion (2018); TAPV Vehicle Rollover (2018)*) |
| **Hazardous** | **B** | Hazard conditions that would reasonably be expected to result in a large reduction in safety margins or functional capabilities, including higher crew workload or physical distress such that crew may not be relied upon to perform tasks accurately or completely. Could result in death or major injury (incapacitation) to land equipment occupants or major damage to a land equipment system. Could result in death or major injury (incapacitation) to ground personnel or the general public. *(e.g. LAV 6.0 Engine Compartment Fires (2021))* |
| **Major** | **C** | Hazard conditions that would reasonably be expected to result in a moderate reduction in safety margins or functional capabilities, including a moderate increase in crew workload or physical distress impairing crew efficiency. Possible physical distress, including injuries to occupants or minor damage to a land equipment system. *(e.g. LAV 6.0 Excessive Noise (2018))* |
| **Minor** | **D** | Hazard conditions that would not significantly reduce land equipment safety, but would reasonably be expected to result in a slight reduction in safety margins or a slight increase in crew workload. *(e.g. MSVS SEV Kitchen – Carbon Monoxide Hazard (2018))* |
| **Negligible** | **E** | No effect on safety. Negligible effect on safety margins. |

Source: Department of National Defence, *10001-1 DGLEPM System Safety Program* (Ottawa: DND Canada, draft), 1.

**Table D.2 – Land Hazard Probability Definitions (Qualitative)**

| Description | Level | Qualitative Definition | Land Equipment Product | Life of Entire Fleet | Individual Vehicle Crew Career | All Exposed Personnel |
|---|---|---|---|---|---|---|
| **Frequent** | 1 | Likely to occur many times. | Expected to occur many times during the operational life of an individual land equipment | Occurs continuously to the entire fleet | Expected to occur many times during an individual's career | Occurs continuously to the entire population |
| **Probable** | 2 | Expected to occur one or more times | Expected to occur one or more times during the operational life of an individual land equipment | Likely to occur several times per year to the entire fleet | Expected to occur one or more times during an individual's career | Likely to occur one or more times per year to the vehicle crews population |
| **Remote** | 3 | Unlikely, but possible to occur | Unlikely, but possible to occur during the operational life of an individual land equipment | May occur one or more times per year to the entire fleet | Unlikely, but possible to occur during an individual's career | May occur one or more times per year to the vehicle crews population |
| **Extremely Remote** | 4 | Not expected to occur | Not expected to occur during the operational life of an individual land equipment | May occur one or more times during the entire operational life of the entire fleet | Not expected to occur during an individual's career | May occur one or more times to the entire vehicle crew population |
| **Extremely Improbable** | 5 | So unlikely, it may be assumed that it will never occur | So unlikely, it may be assumed that it will never occur during the entire operational life of all land equipment of the type | | | |

Source: Department of National Defence, *10001-1 DGLEPM System Safety Program* (Ottawa: DND Canada, draft), 1

# ANNEX E – PRICIEG ASSESSMENT CRITERIA FOR EQUIPMENT

## 6. E – Equipment, Support, Sustainability

| |
|---|
| Equipment considerations here might include equipment in support of construction or in support of Information Management (IM)/Knowledge Management (KM) systems projects.<br><br>Equipment projects need situational awareness on support analysis work and conclusions leading to the support concept, acquired service investments etc.<br><br>The Programme Management Board (PMB) needs to know what issues and efforts will be required to ensure long term sustainability.<br><br>This part of the PRICIEG Annex shall also include the latest detailed costing data available to inform Senior Managers exactly what we know, the accuracy of what we know, and the work remaining to get the best cost data that we can. Tabular formats are acceptable and shall have been endorsed, but not necessarily "approved, by DG Financial Management staff in advance.<br><br>**To delete this guidance text box, right-mouse click within this box, select Delete Rows.** |

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**Figure E.1 – PRICIEG Assessment Criteria for Equipment**

Source: Department of Defence, Project Approval Directive, last modified 20 November 2022, PRICIEG Annex Template

Conduct a cost-benefit analysis for each option taking into account costs, benefits, and risks. Cost-Benefit Analysis is a costing approach that tries to determine the relative benefits of one course of action when compared to another. Based on the costs established for each option, describe how those costs are weighed against the benefits.

**Performance:** Defence equipment that is operationally ready and mission capable;

**Value for Money:** The required Outcomes (i.e. fitness for purpose and quantity) are procured at a price commensurate with the market rate for comparable procurements:

- Smart Buyer
- Balanced Risk
- Efficiency
- Incentives
- Continuity
- Fair Market Value
- Cost for Capability
- Benchmark against other Military
- Other

**Flexibility:** An adaptable and scalable support system that can readily be adjusted to changes in operational requirements and/or operating budgets:

- Scalability
- Plan B
- Evolution
- Access to Intellectual Property
- Value of Intellectual Property
- Surge requirement
- Others

**Economic Benefits:** Leverage industrial benefits from Defence procurements to create jobs and economic growth for companies in Canada.

Some examples include:

> **Cost-effectiveness**—Demonstrates, in financial terms, improvements in performance or in service delivery; shows whether the benefits from the investment outweigh its costs.
>
> **Displaced or avoided costs**—Compares the proposed system's costs to those of the system it would displace or avoid; may justify the proposal on a least-cost basis if it can be assumed that the new system will have as many benefits as the current system.

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**Figure E.2 – Cost-Benefit Analysis Considerations**

Source: Department of Defence, Cost-Benefit Analysis Template, last accessed 7 February 2023, https://collaboration-vcds.forces.mil.ca/sites/dspp/pad/PAD%20Templates%202019/FULL%20Template%20-%20Business%20Case%20Analysis%20ENG.docx

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