Modeling and Simulation of Canadian Forces Operational Energy Consumption

In Support of the Defence Operational Energy Strategy Development

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Defence R&D Canada
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Operational Research & Analysis

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Abstract

This paper presents a framework for analyzing the Canadian Forces (CF) operational energy demand. Operational energy is the energy required for training, moving, and sustaining military forces as well as fueling tactical power generators and powering weapons platforms. The study examined the CF operational energy for expeditionary operations and focused particularly on fuel demand. A fuel consumption prediction model was developed and a typical operational scenario was constructed using historical deployments to forecast operational energy demand. A Monte Carlo simulation framework was also developed to simulate various operational characteristics such as location and duration of deployments and fuel consumption rates. The study indicated that the most prevalent fuel consumption in CF expeditionary operations is aviation fuel, followed by fuel for ground systems, and ships. It also revealed that particular attention should be given to the employment phase of operations for potential fuel consumption optimization. The study provided insights and better understanding of the energy consumption patterns of CF expeditionary operations in support of the Canadian Defence Operational Energy Strategy development.

Résumé

Ce document présente un cadre visant à analyser les besoins en énergie opérationnelle des Forces canadiennes (FC). L’énergie opérationnelle se définit par l’énergie nécessaire à l’entraînement, au déplacement et au maintien des forces, de même qu’à l’alimentation des génératrices tactiques et des plateformes d’armes. L’étude portait sur l’énergie utilisée par les FC lors d’opérations expéditionnaires, avec une attention particulière à la demande en carburant. Un modèle de prédiction de la consommation de carburant et un scénario opérationnel classique ont été créés selon des déploiements antérieurs afin de prévoir les besoins en énergie opérationnelle. Un cadre de simulation Monte Carlo a également été élaboré dans le but de simuler diverses caractéristiques opérationnelles telles que le lieu et la durée des déploiements et les taux de consommation du carburant. L’étude a révélé que les aéronefs sont les véhicules consommant le plus de carburant lors d’opérations expéditionnaires des FC, suivi par les systèmes terrestres et les navires. Il a également été noté qu’une attention particulière devait être portée sur l’étape d’exploitation pour une possible optimisation de la consommation de carburant. L’étude a offert un point de vue ainsi qu’une meilleure compréhension du profil de consommation d’énergie lors d’opérations expéditionnaires des FC, en appui au développement de la stratégie énergétique opérationnelle de la Défense au Canada

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Executive summary

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Ahmed Ghanmi; DRDC CORA TM 2013-062; Defence R&D Canada – CORA; April 2013.

Introduction

Operational energy is defined as the energy required for training, moving, and sustaining military forces and weapons platforms in operations. This energy also includes the demand from tactical power systems and generators in forward operational bases. Operational energy is at the same time a critical enabler and a logistical constraint for military operations. Indeed, energy is essential to power weapons and equipment, expeditionary bases, and to give mobility to ground vehicles, aircraft, naval vessels, and other platforms. Such systems require at least one order of magnitude more energy than during World War 2 due to higher information technology density. Consequently, the increasing demand for operational energy significantly decreases the sustainability of military forces, as well as their operational capabilities and effectiveness. At the operational and tactical levels, energy logistics have proven vulnerable to attacks in recent conflicts. The demand and cost of military operational energy have increased considerably over recent decades, creating several logistical challenges on the battlefield. Indeed, increased operational energy demands drive thicker logistics tails that can slow operations, limit manoeuvrability and deployability, tie up force structure in combat support, create untenable force protection requirements, expose personnel to serious and unnecessary risks, and reduce the likelihood of mission success.

In Canada, how energy is used and managed as a strategic resource within a defence context has been the subject of growing interest both domestically and among Allies. The Department of National Defence (DND) is developing a Defence Operational Energy Strategy (DOES) with the aim of enhancing operational readiness, capabilities and resiliency of defence to achieve its roles and missions in defending Canada, North America, and contributing to international peace and security. The DOES considers energy issues holistically, under a common vision and framework that seeks to integrate existing and planned initiatives for improving energy efficiency and effectiveness, while building a culture of energy awareness and incorporating energy issues in the decision-making process.

One of the requirements for developing an energy strategy is the establishment of a baseline for energy consumption data. Baselining is the act of measuring energy usage at a determined level of detail for the purpose of establishing a benchmark for future comparison purposes. To determine a baseline for energy consumption, historical energy data should be captured and consumption trends should be analyzed. While energy usage data for the Canadian Forces (CF)

domestic infrastructure and operations has been collected for several decades, little information about energy data for expeditionary operations is available in the DND databases. Although fuel transaction costs were recorded, only data for specific operations were recorded so far. To address the data availability issues, modeling and simulation methodologies could used to determine the expected operational energy consumption for various CF deployment scenarios with specific energy efficiency parameters.

Objectives

The objective of this study is to develop a framework for analyzing the operational energy consumption, particularly fuel requirements for expeditionary operations

Method

A fuel consumption prediction model was developed and a generic operational scenario was constructed using historical CF operations to forecast fuel requirements for expeditionary operations. A Monte Carlo simulation framework was also developed to simulate various deployment characteristics.

Results

The analysis indicated that the expected fuel consumption for a 3-year scenario in failed and failing states would be 260 million litres (or $408 million). The most prevalent fuel consumption in CF expeditionary operations would be aviation fuel (54%), followed by diesel (38%) and ship's fuel (8%). Given that the analysis was conducted using a generic scenario with different assumptions on operational data and asset characteristics, the fuel consumption results should be interpreted as indicative estimates.

The analysis also revealed that most of the fuel required for expeditionary operations would be consumed during the employment phase (84%). As such, particular attention should be given to this phase for potential fuel consumption optimization. In particular, during the employment phase 40% of the overall fuel consumption would be for aviation fuel, 38% for diesel, and 6% for ship's fuel. The deployment and the redeployment phases account only for 9% and 7%, respectively.

The framework was used to test the impact of different target examples on fuel consumptions for military compounds, ground vehicles, and legacy platforms. The analysis indicated that significant fuel consumption and cost for military compounds (e.g., 40%) could potentially be reduced through various operational initiatives in the short term such as installation of energy efficient structures, use of tactical intelligent power management systems, use of efficient tactical power generator systems, and culture change. It is also expected that fuel savings in military compounds would reduce the number of convoys in theatre and could be transformed into greater combat efficiency.

Potential fuel consumption reductions for ground vehicles could also be achieved through efficiency programs such as insertion of energy technologies, incorporation of energy metrics in future acquisition processes, and culture change. Fuel consumption reductions for legacy platforms are more complex and would be achieved in a longer term. Finally, the study indicated

that if the scenario involved the deployment of fighter jets, aviation fuel consumption would be much larger. Initiatives to reduce fuel consumption for these aircraft would be through increased used of simulators in trainings, for example.

Future work

The study provided insights and better understanding of the fuel consumption patterns for CF expeditionary operations in support of the Canadian DOES development. Future work could include a cost-risk-benefit analysis for implementing different energy measures; analysis of energy consumptions for domestic operations, trainings; as well as an examination of other energy types and contracted lift costs. Another future work direction could also involve the refinement of the model to include sensitivity analysis of the input variables using a gradient vector approach and to indentify those variables that have larger impact on the overall fuel consumption results.

Sommaire

Modeling and Simulation of Canadian Forces Operational Energy Consumption

In Support of the Defence Operational Energy Strategy Development

Ahmed Ghanmi; DRDC CORA TM 2013-062; R & D pour la défense Canada – CARO; avril 2013.

Introduction

L’énergie opérationnelle se définit par l’énergie nécessaire à l’entraînement, au déplacement et au maintien des forces, de même qu’à l’exploitation des plateformes d’armes et à l’utilisation des génératrices et des systèmes d’alimentation tactiques. Quoiqu’indispensable, elle comporte des contraintes pour les opérations militaires. En effet, l’énergie est essentielle pour alimenter les armes, l’équipement et les bases expéditionnaires, ainsi que pour ravitailler les véhicules terrestres, les aéronefs, les navires et les autres plateformes. De tels systèmes requièrent au moins un ordre de grandeur supérieur en énergie, car la technologie de l’information est plus dense que lors de la Seconde Guerre mondiale. Ainsi, l’augmentation des besoins en énergie opérationnelle réduit considérablement le maintien des forces militaires, de même que l’efficacité et les capacités opérationnelles de ces dernières. D’un point de vue opérationnel et tactique, la logistique de l’énergie s’est montrée vulnérable face aux attaques survenues lors de récents conflits. Les besoins en énergie opérationnelle, ainsi que ses coûts, ont grandement augmenté au cours des dernières décennies, ce qui présente de nombreuses difficultés logistiques sur les champs de bataille. La forte demande en énergie opérationnelle exige de plus grandes chaînes de logistique, ayant pour effet de ralentir les opérations, de restreindre la manœuvrabilité et la déployabilité, d’immobiliser la structure des forces dans l’appui au combat, de créer des besoins de protection des forces indéfendables et d’exposer les militaires à de graves dangers inutiles, en plus de réduire les chances de réussite des missions.

La manière dont le Canada utilise et gère l’énergie en tant que ressource stratégique dans un contexte de défense suscite de plus en plus d’intérêt au pays, ainsi que parmi les alliés. Le ministère de la Défense nationale (MDN) élabore actuellement une stratégie énergétique opérationnelle de la Défense (SEOD) dans le but d’améliorer l’état de préparation opérationnelle, les capacités et la résilience de la défense. Cette stratégie permet également au Ministère d’assumer son rôle dans la défense du Canada et de l’Amérique du Nord, en plus de participer à des missions qui contribuent à la paix et la sécurité internationales. La SEOD examine les enjeux relatifs à l’énergie dans son ensemble, en adoptant une vision et un cadre communs, afin d’intégrer des initiatives existantes et prévues pour améliorer l’efficacité énergétique, tout en mettant en place une culture de sensibilisation à l’énergie et en intégrant des facteurs liés à l’énergie dans le processus décisionnel.

Une des exigences pour l'élaboration d'une stratégie énergétique consiste à établir une base de référence pour les données sur la consommation d'énergie. Il s'agit de mesurer cette dernière à un certain niveau de détail et d'établir un point de repère à des fins de comparaison. Pour ce faire, il faut recueillir des données historiques sur l'énergie et analyser les tendances de consommation. Les données liées aux opérations et aux infrastructures nationales des Forces Canadiennes (FC) sont compilées depuis de nombreuses décennies, mais très peu de renseignements sur les opérations expéditionnaires sont disponibles dans les bases de données du MDN. Même si les coûts de transaction du carburant ont été enregistrés, seules les données d'opérations spécifiques ont été conservées jusqu'à maintenant. Pour résoudre les problèmes liés au manque de données, la modélisation et la simulation permettraient de déterminer la consommation d'énergie opérationnelle prévue pour divers scénarios de déploiement des FC, avec des paramètres d'efficacité énergétique précis.

Objectifs

L'objectif de cette étude est d'élaborer un cadre méthodologique permettant d'analyser la consommation d'énergie opérationnelle, en particulier le carburant nécessaire lors d'opérations expéditionnaires.

Méthode

Un modèle de prédiction de la consommation de carburant et un scénario opérationnel classique ont été créés selon des déploiements antérieurs afin de prévoir les besoins en énergie lors d'opérations expéditionnaires. Un cadre de simulation Monte Carlo a également été élaboré dans le but de simuler diverses caractéristiques propres aux déploiements.

Résultats

L'analyse révèle que la consommation projetée de carburant serait de 260 millions de litres (ou 408 millions de dollars) sur trois ans dans le contexte d'États défaillants ou d'États en déroute. Le carburant aviation serait le type de carburant le plus utilisé dans le cadre des opérations expéditionnaires des FC (54 %), suivi du carburant diesel (38 %) et du carburant des navires (8 %). Étant donné que l'analyse repose sur un scénario général faisant intervenir différentes hypothèses concernant les données opérationnelles et les caractéristiques des ressources, les résultats au regard de la consommation de carburant devraient être considérés comme des estimations indicatives.

Par ailleurs, les résultats indiquent que la plus grande part du carburant nécessaire aux opérations expéditionnaires serait consommée durant la phase d'emploi (84 %). Par conséquent, il faudrait se concentrer tout particulièrement sur cette phase pour éventuellement optimiser la consommation de carburant. Plus précisément, à la phase d'emploi, 40 % du carburant consommé serait du carburant aviation, 38 %, du carburant diesel et 6 %, du carburant pour les navires. Les phases de déploiement et de redéploiement représenteraient seulement 9 % et 7 % respectivement de la consommation totale de carburant.

Le cadre méthodologique a été utilisé pour tester les effets de différents objectifs sur la consommation de carburant des complexes militaires, des véhicules terrestres et des anciennes plateformes. D'après les résultats de l'analyse pour le volet des complexes militaires, dans les cas

où la consommation de carburant et les coûts sont relativement élevés (p. ex. 40 %), il serait possible de réduire à court terme ces coûts grâce à diverses mesures opérationnelles comme l'installation de structures éconergétiques, l'utilisation de systèmes tactiques intelligents de gestion de l'énergie, l'utilisation de systèmes tactiques efficients de production d'énergie et un changement de culture. On s'attend également à ce que les économies de carburant dans les complexes militaires réduisent le nombre de convois dans le théâtre d'opérations et puissent se traduire par une plus grande efficacité au combat.

Divers programmes d'efficacité énergétique – par exemple l'intégration de technologies énergétiques, l'intégration de paramètres énergétiques dans les démarches d'approvisionnement futures et un changement de culture – pourraient entraîner une diminution de la consommation de carburant des véhicules terrestres. Dans le cas des anciennes plateformes, il serait plus compliqué et plus long de réduire la consommation de carburant. Enfin, les résultats de l'analyse indiquent que si des chasseurs à réaction étaient déployés dans le scénario, la consommation de carburant aviation serait beaucoup plus élevée. Une façon de réduire la consommation de carburant de ces avions consisterait à utiliser davantage les simulateurs dans le cadre de l'instruction.

Recherches futures

L'étude donne un aperçu unique de la consommation de carburant dans le cadre des opérations expéditionnaires des FC et permet de mieux en comprendre les caractéristiques afin d'orienter l'élaboration de la SEOD du Canada. Dans l'avenir, il pourrait être intéressant d'analyser les coûts, les risques et les avantages de la mise en œuvre de différentes mesures énergétiques, d'analyser la consommation d'énergie aux fins des opérations nationales et de l'instruction et d'examiner d'autres formes d'énergie et les coûts des contrats de transport. Une autre recherche potentielle dans le future consiste à améliorer le modèle pour inclure des mesures de sensibilité des variables et pour identifier les variables qui pourront avoir un impact significatif sur l'ensembles des résultats.

Table of contents

List of figures

List of tables

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1 Introduction

1.1 Background

Operational energy is defined as the energy required for training, moving, and sustaining military forces and weapons platforms in operations. This energy also includes the demand from tactical power systems and generators in forward operational bases. Operational energy is at the same time a critical enabler and a logistical constraint for military operations. Indeed, energy is essential to power weapons and equipment, expeditionary bases (all amenities such as heating, cooling, lighting and cooking), and to give mobility to ground vehicles, aircraft, naval vessels, and other platforms. Such systems require at least one order of magnitude more energy due to higher information technology density than during World War 2. Consequently, the increasing demand for operational energy significantly decreases the sustainability of military forces, as well as their operational capabilities and effectiveness. At the operational and tactical levels, energy logistics have proven vulnerable to attacks in recent conflicts.

Operational energy may take the form of fuel for military platforms (e.g., vehicles, aircraft, and ships), electricity for military compounds (e.g., power for information systems) or batteries for dismounted infantry (e.g., soldier system). In addition to operational energy, military forces require energy to operate their domestic infrastructure (e.g., bases, wings) in the form of grid electricity, natural gas, and fuels. Historical energy data indicated that 60% of the Canadian Forces (CF) energy costs during the last decades were for operations and 40% were for infrastructure [1]. Comparative figures of energy consumption and costs were observed for the United States (US) Department of Defense (DoD) and the United Kingdom (UK) Ministry of Defense (MoD) [2].

The demand and cost of military operational energy have increased considerably over recent decades, creating several logistical challenges in the battlefields. Indeed, increased operational energy demands drive thicker logistics tails (e.g., fuel convoys) that can slow operations, limit manoeuvrability and deployability, tie up force structure in combat support, create untenable force protection requirements, and expose personnel to serious and unnecessary risks, and reduce the likelihood of mission success. For example, fuel delivery convoys along vulnerable lines of communication in Afghanistan have often been prime targets for insurgent forces [3]. Protecting these convoys imposes a high logistics burden on combat forces by diverting combat units from direct engagement to force protection missions.

In Canada, how energy is used and managed as a strategic resource within a defence context has been the subject of growing interest both domestically and among Allies. The Department of National Defence (DND) is developing a Defence Operational Energy Strategy (DOES) with the aim of enhancing operational readiness, capabilities and resiliency of defence to achieve its roles and missions in defending Canada, North America, and contributing to international peace and security. The DOES considers energy issues holistically, under a common vision and framework that seeks to integrate existing and planned initiatives for improving energy efficiency and effectiveness, while building a culture of energy awareness and incorporating energy issues in the decision-making process. In a nutshell, the DOES ultimately seeks to strengthen the operational capabilities and resilience of defence while at the same time reducing risks and vulnerabilities where possible and ensuring sustainability.

To develop the operational energy strategy, a working group involving various organizations (Assistant Deputy Minister (Infrastructure and Environment), Assistant Deputy Minister (Materiel), Assistant Deputy Minister (Finance and Corporate Services), Chief of Land Staff (CLS), Chief of Maritime Staff (CMS), Chief of Air Staff (CAS), Canadian Joint Operations Command (CJOC), Defence Research and Development Canada (DRDC), Canadian Force Development (CFD), and Vice Chief of Defence Staff (VCDS)) was established in April 2012. Its mandate is to study energy issues for the Department and provide recommendations for the implementation of an energy strategy for DND and the CF. During the course of the study, the working group has been engaged in various collaborations and discussions with academia, private sectors, other government organizations, and the US DoD in order to better understand the concept, process and requirements for developing an energy strategy for defence.

One of the requirements for developing an energy strategy is the establishment of a baseline for energy consumption data. Baselining is the act of measuring energy usage at a determined level of detail for the purpose of establishing a benchmark for future comparison purposes. To determine a baseline for energy consumption, historical energy data should be captured and consumption trends should be analyzed. While energy usage data for CF domestic infrastructure and operations has been collected for several decades, little information about energy data for expeditionary operations is available in the DND databases. Although fuel transaction costs were recorded, only data for specific operations were recorded so far. To address the data availability issues, modeling and simulation methodologies could used to determine the expected operational energy consumption for various CF deployment scenarios with specific energy efficiency parameters.

1.2 Objective

The objective of this study is to develop a framework for analyzing the operational energy consumption, particularly fuel requirements for expeditionary operations. The methodology used a simulation approach to model various CF deployment scenarios, simulate fuel consumptions, and conduct “what-if” analysis.

1.3 Literature Review

Several studies have been conducted in the literature to address the military operational energy problems. Bochman [3] discussed the operational energy challenges for the US military operations in Iraq and Afghanistan and highlighted the importance of energy efficiency metrics in reducing energy demands and costs. A US energy defence science board conducted several analyses for the DoD to evaluate fuel-efficient technologies for weapon platforms, identify opportunities for reducing fuel demands in operations, and examine options for deploying renewable and alternative energy sources for facilities and deployed forces [4, 5]. These analyses indicated that military requirements and acquisition processes are the areas offering the greatest impact on improving warfighting capabilities through reducing the fuel burden. They recommended the establishment of energy key performance indicators to constrain the battlespace fuel demand and the development of a Fully Burdened Cost of Energy (FBCE) methodology to guide the acquisition investments.

The US Army Materiel Systems Analysis Activity has developed a Fuel Consumption Prediction Model (FCPM) to estimate fuel consumption characteristics and metrics for ground vehicles under various terrains, power-loading conditions, and mission profiles [6]. FCPM has two modules, namely: Item Level Prediction (ILP) and Mission Level Prediction (MLP) modules. The ILP module estimates fuel consumption rates of vehicles as a function of the duty cycle/power demand and the efficiency of the system to fulfill the demand. The MLP module estimates the amount of fuel available and required by a force for a particular given mission profile. Fuel needed for each system in the force (e.g., logistics trucks, armoured vehicles) over a given mission profile is calculated by summing the fuel consumed by all elements of the system and the burn rates for a given condition obtained from the ILP module. The total fuel required by the force is calculated by summing the product of fuel consumed by an individual system over its mission and its system density in the force. FCPM was applied to several major US Army acquisition programs and assisted the Army planning community in revising burn rate performance databases used to generate operational planning factors.

Banfield et al. [7] developed a FBCE framework to support the British Aerospace Systems and the UK MoD energy investigations. The framework was used to assess alternative energy approaches and technologies for MoD through scenario analysis. The framework was also used to assess energy usage on estates, deployed operations (e.g., Afghanistan) and training and to provide insights into the impact of energy burdens in terms of full cost at the point of usage, logistical effort, and greenhouse emissions.

The UK Defense Science and Technology Laboratory has been undertaking development of a methodology to forecast the strategic energy demand for defence excluding nuclear [2]. The energy demand is being assessed in two main components: 1) data sourced directly relating to UK military operations including training, and 2) data sourced directly relating to UK military infrastructure. Different methods of assessing energy demand have been applied to the two components. For operations, the overall approach is to determine a likely sequence of scenarios over the next decades, based on historical likelihood of occurrence, that is consistent with current policy (number and type of concurrent missions). This is performed using the Demand in Deployed Operations approach. Using this approach, future scenario streams are generated stochastically from user inputs for each domain (land, air, and maritime) and the energy demand for each scenario is estimated based on planning assumptions. For infrastructure, actual consumption data are obtained from the Defence Infrastructure Organization and historical trends on energy consumption are identified. From these trends and key future factors (e.g., new equipment, future climate), a forecast of strategic energy demand is extrapolated.

In DRDC, Ghanmi [8] developed an analytical framework for evaluating the FBCE in military operations. The framework used cost estimation techniques to model the FBCE and focused on fuel-based military systems and operations. The FBCE concept could be used to conduct a proper evaluation of the energy costs when assessing different alternatives in military operations and acquisitions as well as to inform decisions on investment programs for the development of efficient energy solutions. Two case studies using CF domestic and deployed operational bases were presented and discussed to demonstrate the methodology. Neill [1] analyzed historical energy consumption data for CF infrastructure operations and developed a strategic framework for exploring alternative energy options for DND and the CF. Amow [9] analyzed the operational energy requirements for a CF Northern base and examined alternative power and energy options for reduced-diesel operations at the base. A further study was performed to analyze energy conservation and integration of heat pump technologies at the Northern base [10]. Electrical consumption was monitored and an energy model of the base was developed to identify key energy flows and potential energy saving opportunities such as upgrading lighting fixtures, controls and building envelope improvements, and impact of using a sea water heat pump system for space heating. Dobias and Po [11] analyzed power requirements for dismounted infantry and explored alternative solutions for AA batteries.

1.4 Report Organization

The paper is organized as follows. The next section presents the DOES framework and highlights the methodology and assumptions for developing a baseline of energy consumption for DND. The subsequent section provides details about the mathematical model developed to predict fuel requirements for CF expeditionary operations. The fourth section presents an analysis of fuel consumptions and the fifth section discusses the impact of different DOES targets. Finally, the sixth section summarizes the study findings and highlights some future work.

2 Defence Operational Energy Strategy

This section discusses the DOES framework and presents the methodology for establishing a baseline of energy consumption for DND and the CF.

2.1 DOES Framework

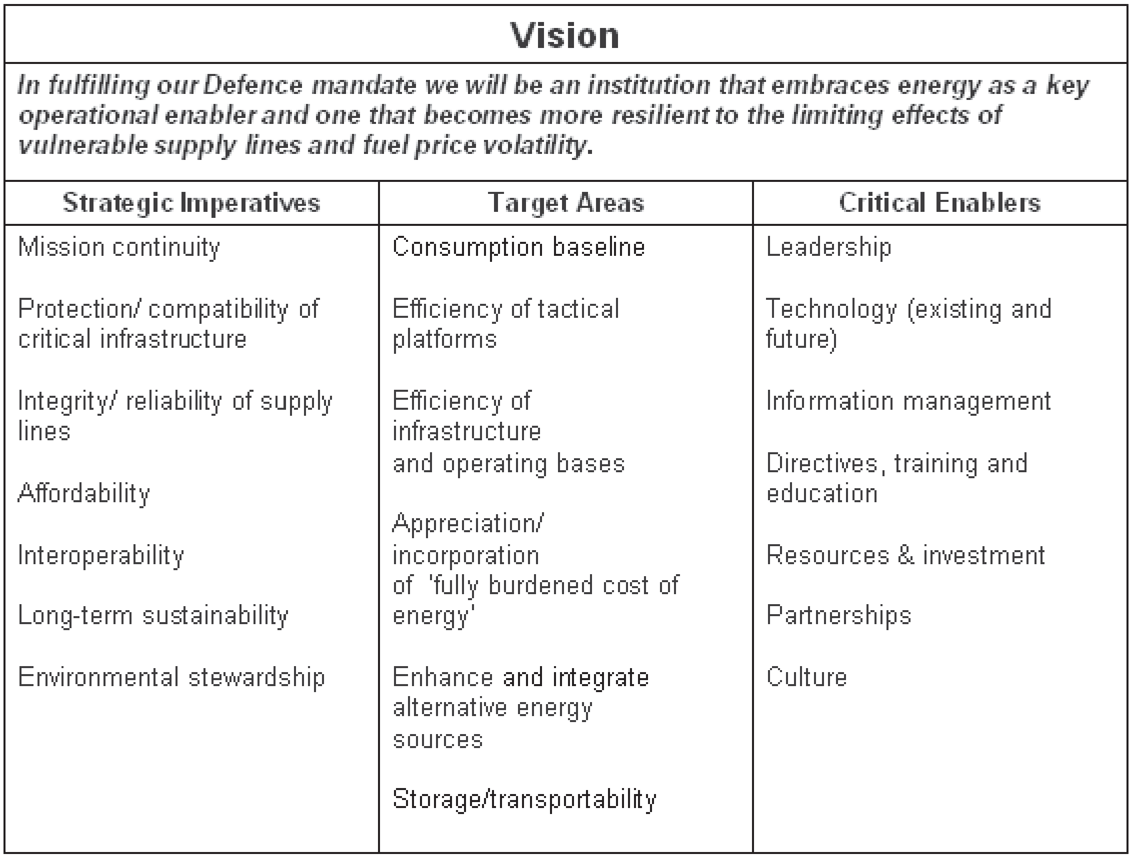
The DOES framework is comprised of a number of components including strategic imperatives, energy targets, and critical enablers. Strategic imperatives refer to the fundamental operational requirements for defence to successfully fulfill its mandate and roles. The prime imperative is mission continuity to maintain the capacity to deliver on enduring operational commitments. Energy considerations play a critical role in ensuring mission continuity by enabling operations to go further, longer, or even faster on the same or reduced fuel loads and thereby expanding tactical reach, eventually increasing operations success. Other strategic imperatives include: the protection and compatibility of critical infrastructure, such as having access to and being compatible with additional energy source types; ensuring the integrity and reliability of supply lines and reducing potential threats to the transportation of fuel where and when it is needed; affordability and the ability to make trade-offs to control the impact of price fluctuations for fuel; interoperability of platforms and energy technology; as well as long-term sustainability of energy supply and environmental stewardship to reduce the defence environment footprint.

Targets are essentially the ways by which the strategic imperatives are met. The DOES identifies a number of target categories including establishing a baseline of energy consumption, improving the energy efficiency for tactical platforms and operating bases, the development of energy performance metrics such as the FBCE that could be used in the acquisition and modeling and simulation processes, investigation of alternative energy sources, and improvement of energy storage and transportability.

Critical enablers are the potential means by which the DOES will be implemented so as to improve energy efficiency in military operations. Success would hinge first and foremost on leadership at all levels and strengthening a culture on energy awareness that would bring energy considerations to the forefront of operational planning. Technology has traditionally had a significant role in defence operations and new developments will continue to shape future trends and bring to bear greater long-term energy efficiencies. Information management and the importance of accessing data for monitoring, tracking and performance measurement are fundamental components to the success of the DOES. Other enablers include establishing directives and instituting the necessary training and education of energy users to optimize 21st-century defence investments. Candidate resources and technologies must be assessed in collaboration, establishing partnerships with supporting agencies at all relevant levels of government, as well as Allies, in order to leverage energy related efforts and support common goals and initiatives.

Table 1 summarizes the DOES vision and highlights the different strategic imperatives, target areas, and critical enablers for establishing an energy strategy. One of the target areas examined in this study is the development of a baseline energy consumption data for DND.

Table 1 DOES vision and components.



<table>
<tr><th colspan="3">Vision</th></tr>
<tr><td colspan="3"><i>In fulfilling our Defence mandate we will be an institution that embraces energy as a key operational enabler and one that becomes more resilient to the limiting effects of vulnerable supply lines and fuel price volatility.</i></td></tr>
<tr><th>Strategic Imperatives</th><th>Target Areas</th><th>Critical Enablers</th></tr>
<tr><td>Mission continuity
Protection/ compatibility of critical infrastructure
Integrity/ reliability of supply lines
Affordability
Interoperability
Long-term sustainability
Environmental stewardship</td><td>Consumption baseline
Efficiency of tactical platforms
Efficiency of infrastructure and operating bases
Appreciation/ incorporation of 'fully burdened cost of energy'
Enhance and integrate alternative energy sources
Storage/transportability</td><td>Leadership
Technology (existing and future)
Information management
Directives, training and education
Resources & investment
Partnerships
Culture</td></tr>
</table>

2.2 Baseline Energy Consumption

Establishing a baseline of energy consumption and the associated costs is a critical component to the design and development of the DOES. The baseline provides a metric to determine how much energy is being consumed, where, and indicators of potential improvements, including opportunities for energy efficiencies having the highest return on investments. This information is essential not only for budget planning and reporting on expenditures, but also for strategic level analysis and decision-making related to the defence operational role, such as force development, strengthening operational readiness, and building a more efficient and resilient CF.

The main objectives associated with establishing a baseline of energy consumption are essentially two-fold:

1. The first objective seeks to develop a baseline of energy consumption that will provide a benchmark of the total energy consumed within Defence and the CF at a determined level of detail. This objective includes establishing energy consumption levels and costs for both the domestic infrastructure and the fleet, as well as for fulfilling the defence operational role of defending Canada, North America and contributing to international peace and security.

2. The second objective will use the baseline as a point of reference to test the potential outcomes of energy targets being developed for the DOES. Once the baseline for energy consumption has been developed, energy targets can be applied to determine the effects on fuel consumption levels, costs, and other operational and logistical effects (i.e., lighten the load, expanding the tactical reach, fewer refuelling imperatives).

One of the challenges for establishing a baseline of energy consumption is the availability of data. There is currently no consolidated data with which to determine total energy consumption across the department of defence and the CF. On the domestic infrastructure side, data on energy usage have been collected annually since 1998-99 and has been traditionally used for the analysis and reporting of compliance obligations with respect to federal initiatives, namely the Federal Sustainable Development Strategy and its predecessors. Data on fuel consumption by the domestic fleet has also been collected as required for the purposes of analyzing requirements of fuel for mobility and energy performance.

What has yet to be examined is the total energy consumption which integrates the data from the domestic infrastructure with the fleet to establish a holistic picture of energy consumption across defence and the CF. In addition, it remains to be fully determined what the total energy consumption is for operational missions in fulfillment of the key roles of defence, both domestically and internationally. As a consequence of the limitations of the current data on energy consumption, the foundation on which to make strategic and operational decisions related to energy issues is fragmented and there is a capacity for improving the metrics for managing energy demands and improving efficiencies within operational requirements.

2.3 Developing a Baseline of Energy Consumption

The key steps for developing a baseline of operational energy consumption for DND are outlined below and summarized in Figure 1.

2.3.1 Establish baseline of actual energy consumption and costs

A baseline of actual energy consumption for defence will be established by combining energy data and expenditures collected by ADM(IE) from the bases and wings on the DND domestic infrastructure (e.g., buildings), as well as data collected by ADM(Mat) Director Fuel & Lubricants on the fuel consumption of the platforms (i.e., the fleet) and expenditures from across the Environments (Navy, Army and Air Force). The data collected for both the infrastructure and the fleet is available for three years (2008 - 2010) and will be combined to provide a snapshot of the total energy used for all domestic DND buildings and platforms. The data can be broken down by source of energy (e.g., aviation fuel, ships fuel, diesel, gasoline, natural gas, electricity, etc), location, and Environment to provide information on defence’s current stock of energy consumption within a domestic context.

The information has been reported through a number of DND information systems, including the Defence Resource Management Information System and the Financial Management Accounting System. However, it is noted the data has not been audited for verification and it is assumed that the data contains a margin of error estimated to be up to 25%.

2.3.2 Establish benchmark of operational energy consumption and costs

Data to establish benchmarks of the defence operational energy demands and costs will be determined through estimates, based on the specific capability requirements of a number of well-defined operational scenarios developed by the CF. These scenarios provide the estimated operational demands based on a combination of military experience and judgement and simulate the conditions and force element requirements necessary to execute the key roles of defence. They have also been approved by the Chief of Defence Staff and are recognized as operationally plausible. Up to eight scenarios had been developed and include, for example, protecting Canadians and domestic sovereignty, supporting major international events, responding to a terrorist attack and supporting civilian authorities during a crisis. Other scenarios included conducting sustained operations for a major international deployment and a surge operation to respond to a crisis in another country for a shorter defined period.

For the purpose of defining the operational energy requirements for defence, up to three scenarios were identified to further develop estimates on the energy consumption and costing. These scenarios include (in order of priority):

1. Sustained operations for an international deployment

2. Surge operations for the provision of disaster relief and security

3. Domestic routine operations (e.g., as required to fulfill the day-to-day operations for defence, including the North)

Additional energy data will be applied to these scenarios, such as the fuel burn rates of the platforms used and energy requirements to establish, sustain and dismantle operations including the energy estimates for soldiers and forward operating bases. A total energy consumption and cost will be determined for each scenario. Energy targets will be applied to these scenarios to determine the change in energy consumption levels and affect on costs as well as operational effects. The use of scenarios will form the basis for estimates of energy demands required to fulfill the three key roles of defence. It is also anticipated that analysis of data will provide indicators as to where potential savings could be made and which opportunities are most likely to have the highest return on investment.

2.3.3 Application of energy targets to test for outcomes

For the baseline of actual energy consumption and the operational estimates of energy usage, the model will test each data set for outcomes to energy consumption levels and costs. Following this initial step, energy targets developed for the DOES will be applied to the data to determine the impact on energy consumption levels, costs, and operational efficiencies. Data analysis will focus on the degree of change, namely the reduction of energy consumption levels resulting from the application of energy targets and expected reduction in fuel expenditures.

2.3.4 Cost-benefit-risk analysis

To complement the data analysis for establishing the baseline of energy consumption, it is recommended that other analysis be conducted for the purposes of facilitating high-level strategic discussions among the senior management and setting up the conditions for success to implement the DOES over the longer-term. Focus areas, or areas of special interests to senior management, could include implications of the energy consumption trends relative to priorities for investments, options for the highest return on investments, and forecasts of energy expenditures.

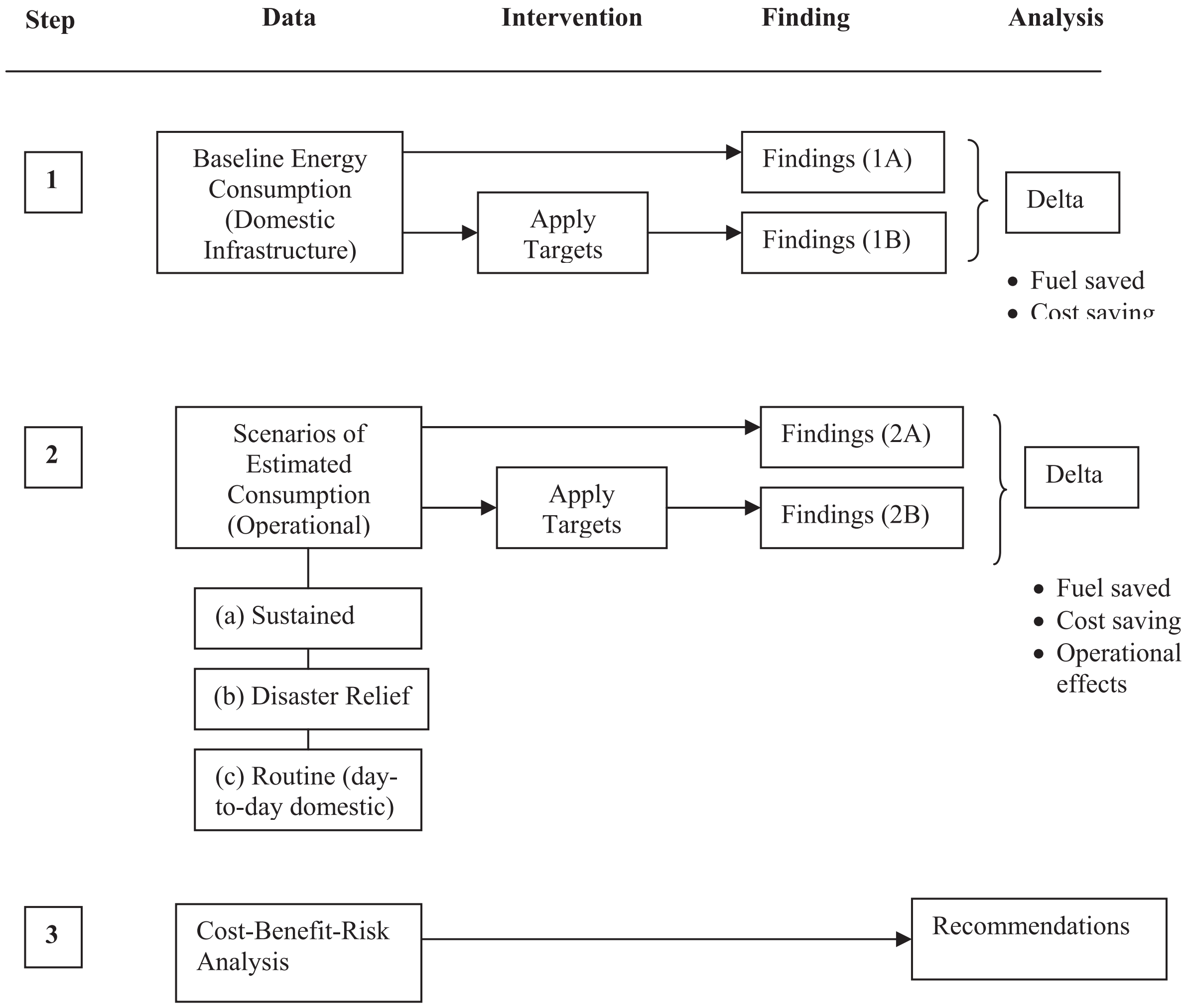


Figure 1 Methodology of baseline energy consumption analysis.

Using this methodology, the baseline energy consumption is the sum of the domestic infrastructure energy consumption and the operational energy consumption for the three scenarios (sustained or expeditionary, disaster relief, and routine) indicated in Figure 1. This paper focuses on the modeling and analysis of fuel consumption for the sustained and disaster relief scenarios. A further study should be conducted to examine fuel consumption of the routine scenario.

3 Fuel Consumption Modeling

This section discusses the methodology and assumptions for modeling and analyzing fuel requirements for CF expeditionary operations and presents the mathematical formulation of a fuel consumption prediction model.

3.1 Methodology

A Monte Carlo simulation framework was developed to study the expected fuel demand of potential future CF expeditionary operations. The framework establishes a common set of parameters describing a typical 3-year period; within this framework, individual parameters such as locations of deployments, frequency of sustainment flights, operating hours of power generator systems, travel distances of ground vehicles, etc., are then generated stochastically. To allow for meaningful statistical evaluation, fuel consumption data are simulated and collected for a large number of randomly generated 3-year intervals.

In the simulation framework, a generic baseline scenario was constructed based on historical CF deployment packages. The scenario considered two distinct force packages—a task force based on a light mechanized battle group and a humanitarian relief package based on the Disaster Assistance Response Team (DART). The simulated task force deployment was based on Operation ATHENA–Canada's contribution to the International Security Assistance Forces in Afghanistan while the DART deployment was based on Operation STRUCTURE–Canada's contribution to the humanitarian assistance operation in response to the tsunami that struck Southeast Asia.

Potential deployment destinations of the task force were determined through the use of 2012 Failed States Index, a combination of 12 social, economic and political/military indicators developed in Fund for Peace (2012)[1]. The geographical distribution of the failed and failing states is presented in Figure 2. Within the simulation framework, probabilities of occurrence were assigned to each country based on the ranking of the failed and failing states. The mapping of the probabilities of occurrence to the indexes of failed and failing states was performed using a simple affine transformation (that is, a linear shift and scaling) of the index subject to a normalization constraint (probabilities must sum to one). To simplify the problem, only the top 60 failed and failing states are considered in the analysis. The impact of adding more failed and failing states on the expected results would be minimal. For the DART package, deployment destinations were based on the world natural disasters distribution developed by the Centre for Research on Epidemiological Disasters[2]. Natural disaster refers to the occurrence of severe natural phenomena such as earthquakes, tsunamis, volcanic eruptions, hurricanes, floods and landslides. Probabilities of occurrence were assigned to countries based on the historical number of disasters.

Each randomly generated 3-year time period within the simulation framework follows a common pattern. At the beginning of the simulation, an Operation ATHENA-like task force is deployed in

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[1] www.global.fundforpeace.org

[2] www.cred.be

a country randomly selected from the set of failed and failing states. This task force will then redeploy to Canada at the end of the operation. A humanitarian assistance deployment will also take place somewhere in the world over the course of the simulation. All deployed forces will be re-supplied via sustainment flights at a rate consistent with historical experience data.

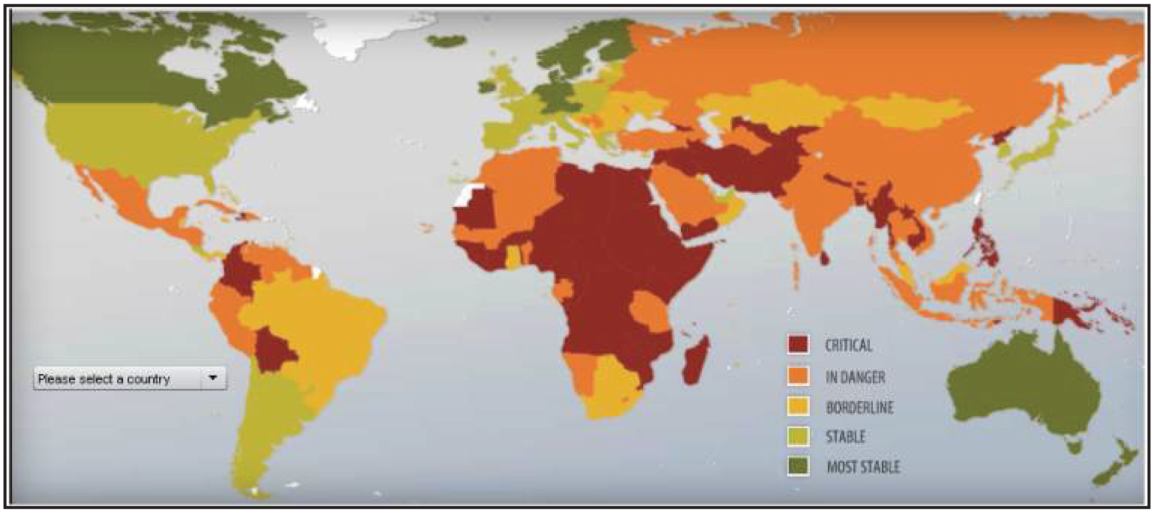

Figure 2 The global distribution of failed and failing states as identified in the 2012 Failed States Index.

3.2 Assumptions

There are several important assumptions that underlie the analysis of the operational energy demand using the simulation framework. Foremost among these, this study was restricted to the analysis of fuel consumption and did not consider other types of energy such as electricity (which could be generated using fuel) and recharging batteries. In military operations, fuel is a critical logistics enabler for mission effectiveness and represents the most important form of energy consumed in theatre, particularly for mobility and power generation activities. While operational energy involves both domestic and international operations, this study focused on the energy demand for expeditionary operations (including a DART) as historical energy consumption data for domestic operations can be found in the CF fuel and lubricants management system.

Historically, the CF used a combination of chartered and native assets for deployment, sustainment and redeployment lift operations. This includes strategic airlift and sealift as well as ground movement. For the purpose of this study, only fuel consumption by native airlift assets (the CF has no native sealift strategic assets) was simulated and calculated. A ratio of native to chartered airlift sorties consistent with historical experience was used in the analysis. Airlift flying times were determined using the great circle distance method, neglecting diplomatic over-flight clearances or weather conditions.

Different types of fuels and lubricants are used in military operations, notably aviation fuel for aircraft and helicopters, diesel for ground vehicles, marine fuel for ships, gasoline, etc. For simplicity, it is assumed that operational fuel requirements are grouped into three main categories, namely aviation fuel, diesel for ground systems, and ship's fuel. Note that the North Atlantic Treaty Organization (NATO) has been developing standards of a single fuel concept for air and ground assets. Lubricant requirements were not considered in the analysis.

Finally, in order to avoid issues with classified information, the conditional probabilities that Canada would respond to crises in a given failed or failing state were deliberately neglected. Inclusion of these effects would tend to place greater weight on areas of strategic importance to Canada while reducing the importance of being capable of rapid deployment to other areas.

3.3 Operational Scenario

The initial deployment of vehicles and equipment during Operation ATHENA was conducted by sealift from Montréal, Canada to Derince, Turkey and then by airlift into Kabul, Afghanistan using a fleet of chartered lift assets. Another set of vehicles was later moved to the theatre of operations using contracted lift and the CF strategic lift aircraft (CC-177). The total number of vehicles deployed to Afghanistan was about 800.

To maintain a close parallel with historical movements, a two-phase deployment consisting of an initial sealift from Montréal to an intermediate Seaport of Disembarkation (SPOD) followed by an airlift to the final Airport of Disembarkation (APOD) at a given failed and failing state was considered in the framework. However, for the purpose of this analysis the airlift was conducted using both chartered aircraft and CC-177. Note that the CC-177 aircraft was not available at the time of the initial deployment of Operation ATHENA but was later used for the sustainment and redeployment lift operations. A number of CC-177 sorties, consistent with the historical Operation ATHENA redeployment lift, were assumed for the deployment. Seven SPODs located at different strategic regions, known as Operational Support Hubs (OSH), are considered for the deployment: Spangdahlem, Germany; Dakar, Senegal; Mombasa, Kenya; Kuwait, Kuwait; Singapore, Singapore; and Kingston, Jamaica.

The Operation ATHENA redeployment was conducted in three phases. High priority items, representing about 25 to 35 CC-177 sorties, were redeployed directly from Afghanistan to Trenton, Canada. Some equipment (e.g., high value items) were moved to an OSH using chartered airlift and CC-177 (about 150 to 200 sorties) and then by chartered sealift to Canada. The remaining equipment and cargo were moved by land to Karachi, Pakistan and then by sea to Montréal. In the simulation framework, it is assumed that the task force redeployed by sea for failed and failing states in the littorals and used the same lines of communication as the Operation ATHENA redeployment for failed and failing states in land-locked countries.

Operation ATHENA personnel were deployed from Trenton to an intermediate staging base (e.g., operational support hub) using the CC-150 strategic lift aircraft, and then to the theatre of operations using the CC-130 tactical lift aircraft. Troop rotations were conducted every six months using the same transportation approach. At the end of the mission, troop redeployed through an intermediate staging base (for decompression) using CC-150 aircraft. During the employment phase, the task force was supported with sustainment flights from Trenton at the historical rate.

For the purpose of this analysis, the baseline scenario also considered the deployment of an Air Force component and a naval task force. For the Air Force component, in addition to the strategic and tactical lift assets (CC-177, CC-150, CC-130) that were used for the deployment, sustainment and redeployment of the task force, a number of tactical helicopters (6 CH-147 Chinook and 8 CH-146 Griffon) and Unmanned Aerial Vehicles (UAVs) were also deployed with Operation ATHENA. The helicopters played several operational roles such as tactical logistics transport, medical evacuation, and rescue operations whereas UAVs were used to support surveillance and reconnaissance missions. For the naval task force, it is assumed that a number of CF frigates were deployed at various locations in support of international activities (e.g., anti-piracy missions). For planning purposes, each ship deploys for a six-month period. Historical CF ship deployments were used as proxies upon which simulated deployments were based.

In addition to the task forces, the baseline scenario also considered the deployment of one DART for a period of three to six months for humanitarian assistance operations. Historically, the CF deployed the DART several times such as in Honduras, after a major hurricane struck, in Turkey, after an earthquake devastated part of the country and in Sri Lanka in the wake of the 2004 tsunami in Southeast Asia. For the earthquake that struck Haiti in 2010, the DART was part of a larger humanitarian operations task force, involving maritime, land and air components. In the baseline scenario, the DART deployment was based on the Operation STRUCTURE package. Operation STRUCTURE's vehicles and equipment were deployed by airlift from Trenton, Ontario to Colombo, Sri Lanka. To maintain a close parallel with historical movements, the DART deployment was conducted by air to a given disaster location using the CC-177 aircraft.

3.4 Fuel Consumption Prediction Model

In the framework, fuel requirements are modeled and simulated for land, air, and maritime operations independently. For land operations, fuel requirements are mainly determined by the daily consumption of ground vehicles and power generation systems of the task forces. NATO has developed a Standard Agreement (STANAG)[3] for computing fuel requirements for an operational base. The STANAG determines a standard estimation for fuel consumption of a military unit called Fuel Consumption Unit (FCU). The FCU represents the quantity of fuel (in litre) required per day for the operation of a given unit under assumed average operating conditions for a given standard performance. The FCU can be calculated using the average consumption rates of all equipment of the unit as follows (assuming a single fuel):

$$FCU = \sum_{v=1}^{V} c_v d_v + \sum_{g=1}^{G} r_g h_g \tag{1}$$

where:

V	number of vehicles in the unit;
G	number of power generators in the unit;
v	index of vehicles;
g	index of generators;
c_v	average fuel consumption rate of vehicle v (L/km);
r_g	average fuel consumption rate of generator g (L/h);
d_v	average daily distance traveled by vehicle v (km/day);

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[3] NATO Standardization Agency, NSA/1083(2008)-DPP/2115

h_g average daily operating hours of generator g (h/day).

For units involved in combat operations or for special terrains or weather conditions other than normal, a series of operational factors affecting the fuel consumption are derived in the STANAG for use in modifying the standard day to fit the combat day. These operational factors are grouped into three categories, namely: combat intensity, terrain and weather factors. Table 2 presents the different operational conditions under each category and their corresponding factors. To calculate the fuel requirement per day of land systems, all FCUs are multiplied by the appropriate operational factors. The total fuel demand of the land task force (F_{Land}) is calculated by multiplying the daily fuel requirements by the mission duration D (in days).

$$F_{Land} = D\sum_{m=1}^{U} B_m T_m W_m FCU_m \tag{2}$$

where:

U number of units in the operation;

m index of units;

B_m combat intensity factor for unit m;

T_m terrain factor for unit m;

W_m weather factor for unit m.

Table 2 Operational factors for fuel consumption estimation.

Combat Intensity		**Terrain**		**Weather**	
Condition	*Factor*	*Condition*	*Factor*	*Condition*	*Factor*
Steady State	1.0	Flat	1.0	Hot	0.9
Urban	1.5	Hilly	1.2	Temperate	1.2
Training	1.8	Cross Country	1.5	Cold	1.4
High Intensity	2.4	Mountainous	1.7	Extreme Cold	1.5

For the Air Force component, fuel requirements are mainly determined by the consumption of assets during the deployment, sustainment and redeployment airlift operations as well as the tactical helicopter and UAV operations in theatre. Currently, the CF would use three types of aircraft (CC-177, CC-150, and CC-130) for airlift operations, in addition to chartered assets. The lines of communication between Trenton and the APOD in failed or failing states would have various nodes (e.g., OSHs) and airlift legs, depending on the type of lift (tactical, strategic) and the kind of move (cargo, personnel). An airlift leg is a distance between two nodes in the lines of communication. For example, the airlift leg between a given OSH and the APOD at destination would be used for tactical lift. For the 3-year scenario, the total fuel demand of the airlift operations ($F_{Airlift}$) can be calculated as follows:

$$F_{Airlift} = \sum_{i=1}^{N}\sum_{j=1}^{M} 2\, n_{ij}\, c_i \frac{d_j}{v_i} \tag{3}$$

where:

N	number of aircraft types;
M	number of airlift legs;
i	index of aircraft types;
j	index of airlift legs;
c_i	average fuel consumption rate of aircraft type i (L/h);
v_i	average speed of aircraft type i (km/h);
d_j	distance of leg j (km);
n_{ij}	number of sorties of aircraft i on leg j.

For tactical air operations using helicopters and UAVs, the fuel consumption ($F_{Tactical}$) is calculated as follows:

$$F_{Tactical} = D \sum_{p=1}^{P} n_p\, x_p\, t_p \tag{4}$$

where:

P	number of asset types (Griffon, Chinook, UAV);
p	index of asset types;
n_p	number of asset of type p;
x_p	average fuel consumption rate of asset type p (L/h);
t_p	average flying hours per day for asset type p (h/day).

For maritime operations, fuel consumptions for a 3-year scenario (F_{Marine}) can be calculated as follows (there are six periods of six months each in the scenario):

$$F_{Marine} = 6 \sum_{k=1}^{S} y_k\, q_k \tag{5}$$

where:

S	number of ships;
k	index of ships;
y_k	average fuel consumption rate of ship k (L/day);
q_k	average number of days per period for ship k (days/period).

The fuel consumption rate per day (y_k) depends on the ship class and its cruising speed (in-harbour, in-transit, and high intensity). In the model, the percentage of time spent by a ship at a given speed in operations is represented by a probability distribution function.

4 Fuel Consumption Analysis

This section presents the data used in the baseline scenario to analyze fuel consumptions for expeditionary operations and discusses the analysis results.

4.1 Scenario Data

Table 3 presents the performance characteristics of the airlift assets used in the baseline scenario. The speed and the fuel consumption rates of the different assets were obtained from the aircraft technical specifications and were represented in the simulation framework by random uniform distributions.

Table 4 depicts a set of the main ground vehicles deployed with Operation ATHENA and their operational characteristics for illustration purposes. Other vehicles and equipment such as engineering vehicles are not presented in Table 4 but were included in the fuel consumption calculation. The fuel consumption rates of vehicles were obtained from their technical specifications whereas the average daily travel distances were estimated by Subject Matter Experts (SMEs) [13, 14] and validated by the DOES working group. The vehicle travel distances are planning figures obtained from SMEs' personal judgements and represent the worst case scenario (upper bound) for distances that could be traveled by military vehicles in operations. As for the airlift assets, random uniform distributions were used to represent stochastic variations of these parameters. The overall list of model variables and their stochastic variations are presented in Annex *B*.

Table 3 Airlift asset performance characteristics.

Transport Aircraft	Cruise Speed (km/h)	Fuel Consumption Rate (L/h)
CC-177	700	9000
CC-130	550	2800
CC-150	600	550

In addition to ground vehicles, the baseline scenario considered the deployment of fifteen 500kW power generators (based on a planning figure of one generator for about 150 to 200 troops) to provide electricity for base operations and fourteen tactical helicopters (eight CH-146 Griffon and six CH-147 Chinook helicopters) and three UAVs to support ground troops. The average daily flying hours of the helicopters and UAVs and the average daily operating hours of power generators were provided by SMEs and were represented by random uniform distributions in the simulation framework. For Operation STRUCTURE, the list of vehicles and equipment is relatively small (with respect to Operation ATHENA) and is not presented in this paper.

Table 4 Ground vehicle operational parameters.

Vehicle Type	Quantity	Fuel Consumption Rate (L/km)	Travel Distance (km/day)
All Terrain Vehicle	28	0.08	100
Truck Utility ¾ Ton	124	0.23	130
Truck Cargo 1.5 Ton	18	0.16	130
Truck Van 1.5 Ton	12	0.23	130
Truck Cargo 2.5 Ton	24	0.57	130
Truck Cargo 10 Ton	11	0.57	120
Armoured Heavy Support Vehicle System (AHSVS)	87	0.82	120
Light Armoured Vehicle (LAV) Bison	32	0.42	130
LAV Coyote	10	0.40	130
LAV APC Wheeled	68	0.40	150
LAV APC Trucked	44	0.75	150
Nyala RG-31	91	0.15	180
Tank Leopard	24	3.4	70
Tractor	20	0.57	80

For the naval task force, the number of ships deployed every six-month period is represented by a probability distribution function based on historical likelihood of occurrence. Figure 3 presents histograms of the number of ships deployed in different regions between 1990 and 2009 [12]. Given that the study focused on expeditionary operations, only ship activities in regions such as Arabian Sea, Mediterranean, Gulf of Aden, Persian Gulf, Indian Ocean, and Red Sea were considered. The panels in Figure 3 do not necessarily reflect the durations of ship deployments rather the density of ship activities at a given region. In the model, the number of frigates deployed to international regions at any given six-month period is represented by a probability distribution function consistent with historical experience. The probability of having 0, 1, 2, 3, or 4 frigates is 0.05, 0.1, 0.3, 0.5, and 0.05, respectively (validated by SMEs).

Three classes of ships (Protector, Iroquois, and Halifax) were considered in the analysis and the probability that a given class is deployed was also determined from historical experience and validated by SMEs (0.1 for Protector, 0.2 for Iroquois, 0.7 for Halifax). The percentage of time spent by a ship at a given speed in operations was also represented by a probability distribution function (0.1 for in-harbor, 0.6 for in-transit, and 0.3 for high intensity).

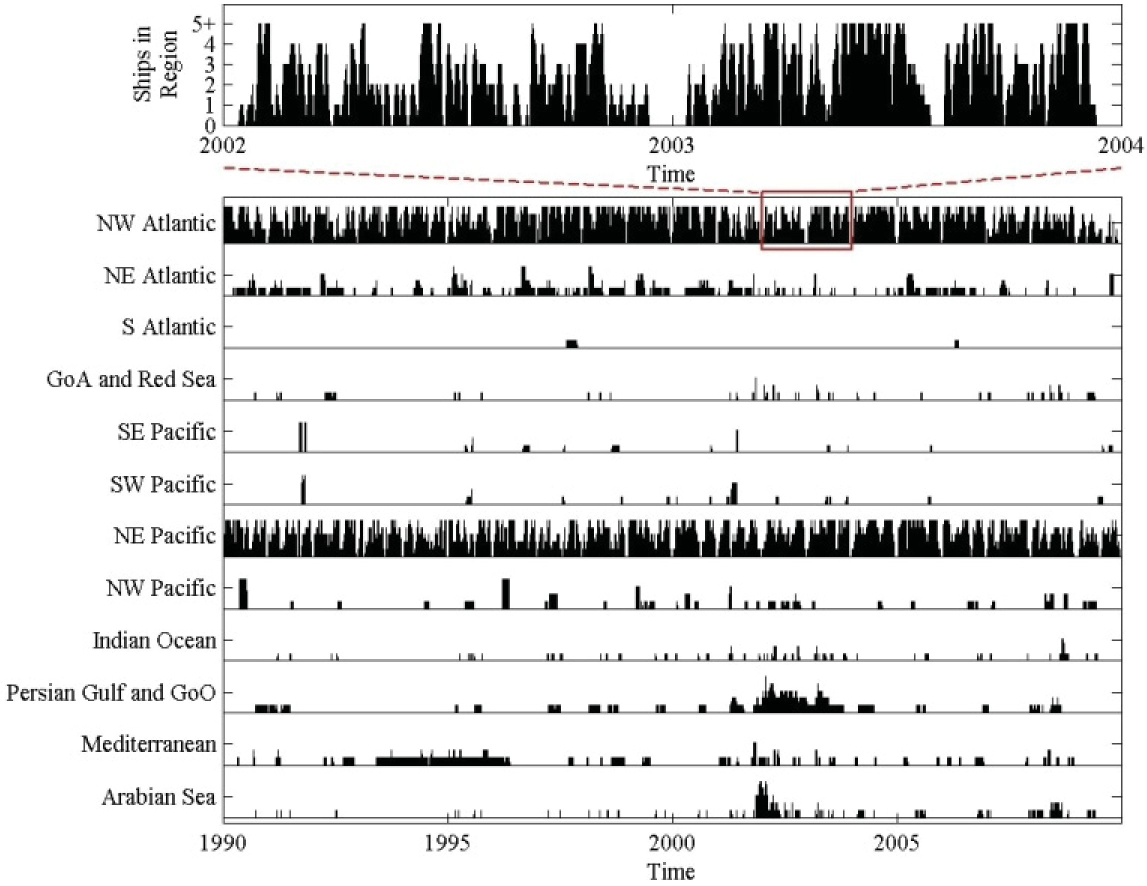

Figure 3 Daily density of ship activities by region (from [12]).

4.2 Total Fuel Consumption

The frequency distribution of the total fuel consumption for the baseline scenario is depicted in Figure 4. On average, about 260 million litres of fuel would be required for supporting an operation ATHENA-like deployed during three years in a failed or failing state, in addition to one DART and a maritime task force deployment. The total fuel requirements include aviation fuel for transport aircraft and tactical helicopters, diesel for ground vehicles and power generators, and marine fuel for ships. The standard deviation of the fuel consumption distribution is 40 million litres and its 95% interval confidence is [180, 340] million litres. The large variations in the fuel consumption results are associated with the distances of the deployment locations. As the deployment distance from Trenton increases, the fuel consumption increases, particularly aviation fuels required for the sustainment lift operations.

It is important to note that the analysis was conducted using a generic scenario with different assumptions on operational data and asset performance characteristics. Therefore, the results of the operational fuel consumption should be interpreted as indicative estimates. In addition, the scenario did not consider fuel consumption associated with contracted assets (e.g., contracted sealift and airlift); therefore results should be carefully interpreted with respect to the scenario assumptions and characteristics.

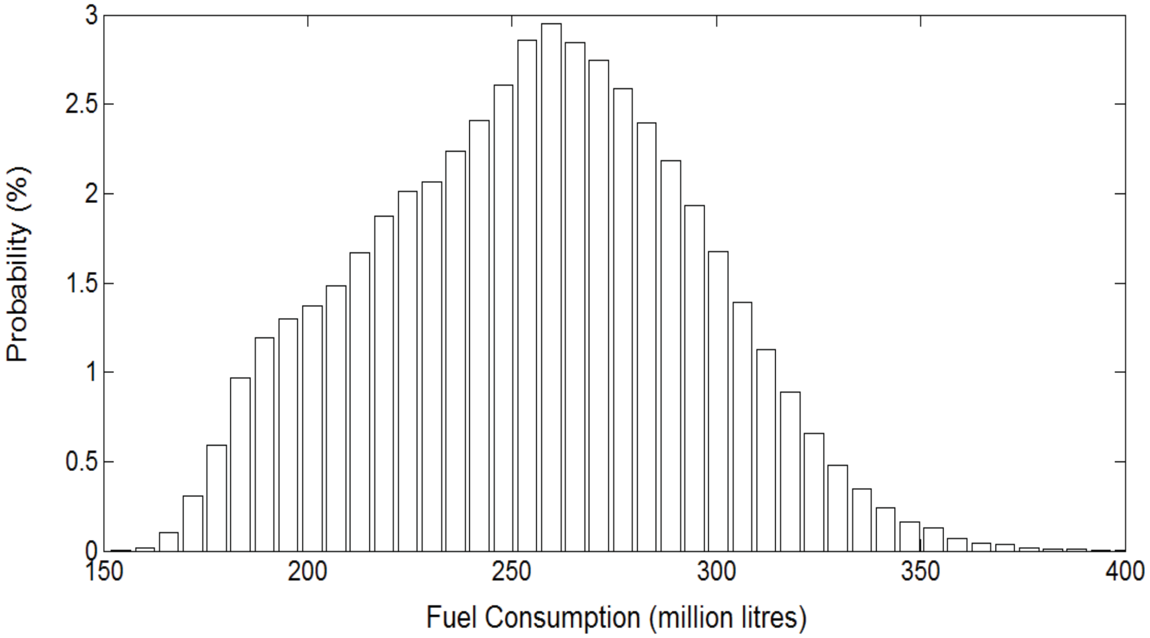

Figure 4 Probability distribution of fuel consumption.

4.3 Fuel Consumption and Cost by Fuel Type

Figure 5 depicts the historical fuel price per litre paid by the CF in Afghanistan between August 2009 and November 2012. Figure 6 presents the fuel consumption and cost grouped by fuel type. The analysis indicated that the most prevalent fuel consumption in CF expeditionary operations would be aviation fuel (54%), followed by diesel for ground systems (38%) and ship's fuel (8%). Using an average historical fuel price of $1.7 per litre for aviation fuel, $1.5 per litre for diesel, and $1.0 per litre for ship's fuel as examples, the expected fuel cost would be $238 million for aviation fuel, $150 million for diesel, and $20 million for ship's fuel as shown in Figure 6. Aviation fuel consumption is mainly driven by airlift operations during the deployment, employment and redeployment operations. While an airlift option would be required for the transport of high priority and sensitive military items, aviation fuel consumption and cost could be reduced through better planning of lift operations and increased use of sealift capability, particularly for low priority items. For ground system operations, potential fuel consumption reduction could be achieved through various operational efficiency initiatives and efficient technologies. In contrast with aviation fuel and diesel, fuel consumption and cost for ships would be comparatively low in this scenario. However, they might be significant for domestic maritime operations as Canada has three large coasts.

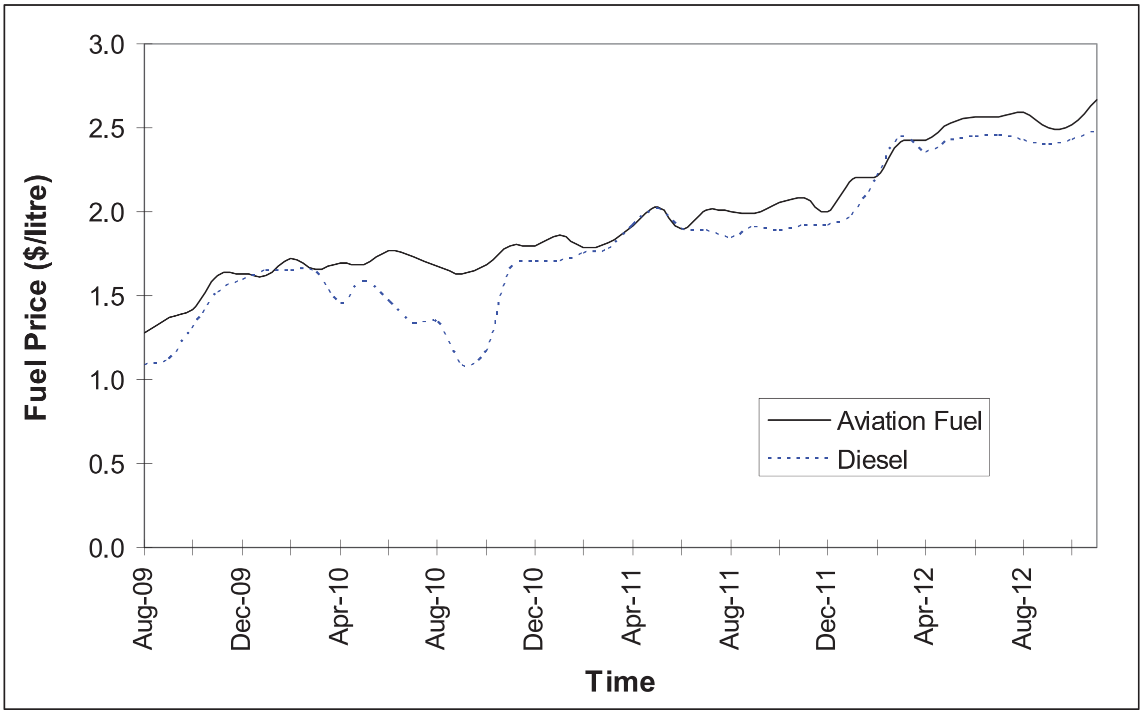

Figure 5 Historical fuel price distribution in Afghanistan.

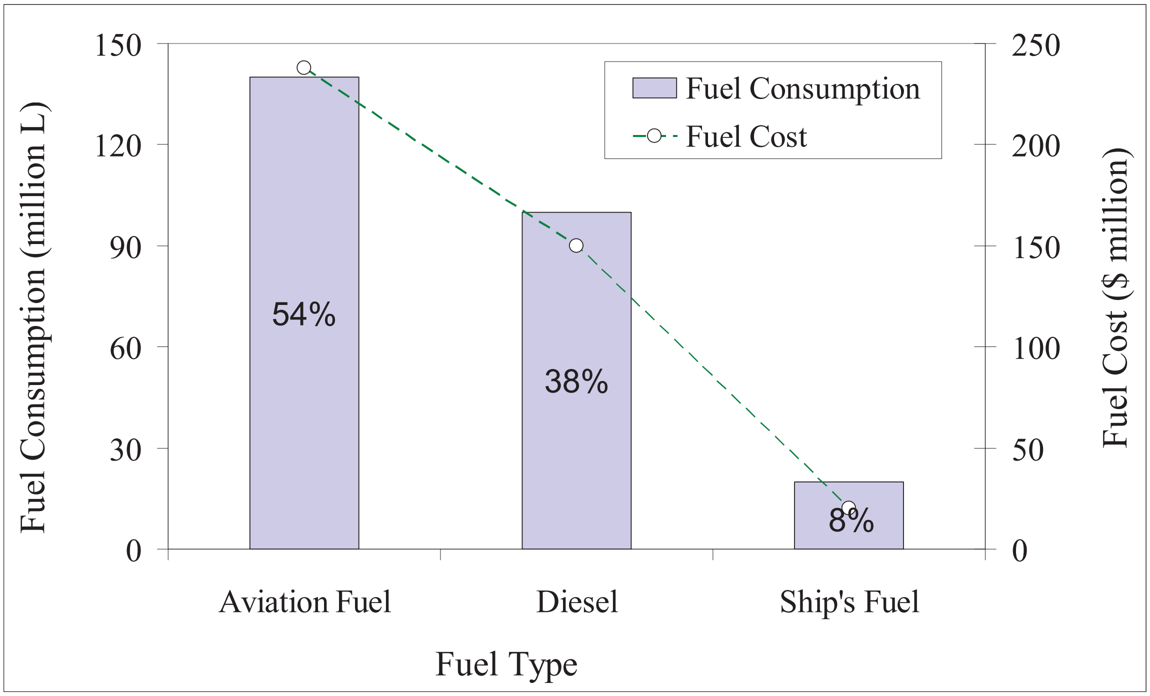

Figure 6 Fuel consumption and cost by fuel type.

4.4 Fuel Consumption by Operational Phase

The total fuel consumption distribution at each operational phase (deployment, employment, and redeployment) is presented in Table 5. The analysis revealed that most of the fuel consumption for deployed operations would occur during the employment phase (84%). As such, particular attention should be given to the employment phase for potential fuel consumption optimization. In this phase, fuel consumption is mainly driven by sustainment lift operations, power generation operations, ground vehicles and helicopter activities. In the employment phase, 40% of the overall fuel consumption would be for aviation fuel (30% for transport aircraft and 10% for tactical helicopters), 38% for diesel (21% for power generation and 17% for ground vehicles) and 6% for ship's fuel as indicated in Table 5. The deployment and the redeployment phases account only for 9% and 7%, respectively. Fuel consumption during the redeployment phase is slightly lower than the one in the deployment phase because of the assumption that most of the materiel will be returned through contracted sealift for littoral failed and failing states.

Table 5 Fuel consumption by operational phase and fuel type.

Operational Phase	Fuel Consumption (%)		
	Aviation Fuel	Diesel	Ship's Fuel
Deployment	8	0	1
Employment	40	38	6
Redeployment	6	0	1

4.5 Global Distribution of Fuel Consumption

Figure 7 presents the fuel consumption distribution with the mission distances calculated using the great circle distance between Trenton and the capital cities of failed and failing states. The fuel consumption variations at each location are associated with the stochastic variations of the scenario parameters (e.g., aircraft speed, fuel consumption rates, vehicle travel distance, etc.). Three potential regions (A, B, C) can be identified as shown in Figure 7:

1. Regions (A) within a distance of 2000 to 5000 km from Trenton. They represent failed and failing states in Central America, West Europe and West Africa. The expected fuel consumption in these regions would be about 200 million litres.
2. Regions (B) within a distance of 7000 to 10,000 km from Trenton. They include failed and failing states in Europe, Africa, South America, and the Middle East. The expected fuel consumption for these deployments would be about 250 million litres.

3. Regions (C) within a distance of 11,000 to 16,000 km from Trenton. They correspond to failed and failing states mainly in Asia. The expected fuel consumption for these deployments would be 300 million litres.

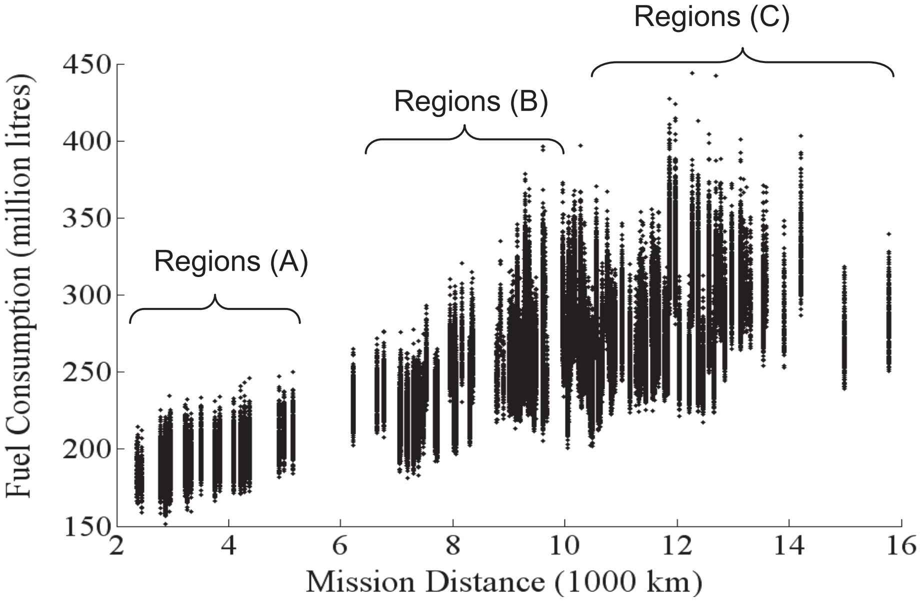

Figure 7 Fuel consumption distribution with mission distance.

4.6 Force Planning Scenario

The CF have developed Force Planning Scenarios (FPSs) to provide a range of fictional domestic, continental and international situations in which they could be called upon to conduct operations. The FPSs describe plausible, relevant and challenging future operational situations to bring greater precision to military assessments of the capabilities and force structure that may be required to support a particular operation. Through the analysis of scenarios, force planners make informed decisions about what requirements the CF might need for future operations, explore different options for delivering military capability and set a coherent force structure for what lies ahead.

A sensitivity analysis was conducted to examine baseline fuel requirements using the FPS for expeditionary operations. The scenario considers the deployment of a number of CF-18 fighter jets with a task force similar to the Operation ATHENA package. The aircraft will likely arrive (self-deploy) shortly after the theatre is established and will leave prior to theatre deactivation. They would also likely be rotated back to Canada several times for maintenance. Fuel consumption associated with the fighter jets' deployment was simulated using the baseline 3-year scenario in failed and failing states. The operational parameters such as the number of fighter jets, consumption rates, and average number of flying hours per day were based on the CF historical Operation MOBILE deployment for the enforcement of the no-fly zone in Libya in 2011. In the scenario, it is assumed (validated by SMEs) that six CF-18 fighter jets would be deployed for about two years and rotated back to Canada two to three times for maintenance operations.

The analysis indicated that the deployment of the fighter jets in failed and failing states for about two years would require 72 million litres of fuel on average. The fuel demand calculation includes fuel consumptions during deployment, redeployment, rotation for maintenance, and employment of the CF-18 aircraft, representing about 50% of the aviation fuel required for the task force deployment. The historical fuel consumption of the CF-18 jets during Operation MOBILE was about 18 million litres for a period of six months, which is comparable with the simulation results (72 million litres / 4 = 18 million litres per six months).

5 Fuel Consumption Targets Analysis

Different DOES targets were developed to assess their potential effects on fuel consumption levels, costs, and operational efficiencies. This section examines and discusses the impact of three potential targets, namely: 1) reduction of fuel demands in military compounds, 2) efficiency of ground vehicle fleets, and 3) efficiency of legacy platforms. The analysis focused on the degree of change, namely the reduction of energy consumption levels resulting from the application of energy targets and expected savings in fuel expenditures.

5.1 Reduction of fuel consumption in military compounds

Initiatives to reduce fuel consumption in military compounds would include installation of energy efficient structures (e.g., domes, spray-foam insulations, efficient heating, ventilation and cooling systems); use of tactical intelligent power management systems to manage power generation, storage and distribution operations; use of efficient tactical power generator systems (e.g., variable speed generators); and culture change (creating a cultural climate that values energy as a mission-critical resource that must be managed). The impact of these initiatives was assessed using the following targets as examples:

1. Reduce the energy consumption required per person by 20% through culture change and efficient structures. In this case, the total power generation capacity for military compounds would be reduced by at least 1500 kW.
2. Improve the efficiency of tactical power generator systems by 20% through technology insertion (i.e., reduce the generator consumption rates by 20%).
3. Improve the efficiency of power management, storage and distribution systems by 10%. This could potentially reduce the daily operating hours of generators by 10%.

The assessment of the impact of these targets is provided by the DOES working group based on allies' assumptions. Using these targets, the combined fuel consumption reduction in military compounds would be on the order of 40% (or 22 million litres) on average for the 3-year scenario, which represents a significant improvement of the operational energy efficiency for CF expeditionary operations. It is also expected that reduction of fuel requirements in military compounds would reduce the number of delivery convoys and escort assets.

5.2 Efficiency of ground vehicle fleets

As for military compounds, initiatives to improve efficiency of ground vehicle fleets would include insertion of efficient technologies (e.g., use of light weight materials to enhance the vehicle's fuel consumption performance, payload, range, optimized types, and agility), incorporation of energy metrics (e.g., FBCE) in future acquisition programs, and culture change for operating the vehicles. In contrast with energy initiatives for military compounds, which could be implemented in short terms, the vehicle fleet's measures are long-term goals and require the development of procurement programs. For the purpose of this analysis, the impact of these initiatives on vehicle's fuel consumptions was examined using the following targets to demonstrate the methodology:

1. Increase the average distance per litre of fuel used for vehicles by 20% through technology insertion, energy metrics and culture change. For example, this target was applied to several vehicle fleets in Table 4 such as all terrain vehicles, truck utility vehicles, and logistics trucks (truck cargo 1.5 ton, truck van 1.5 ton, truck cargo 2.5 ton, truck cargo 10 ton, and truck AHSVS).
2. Reduce the number of logistics and escort convoys by 10% following the implementation of energy efficiency initiatives in military compounds as discussed in the previous section. For example, this target was applied to the logistics fleet of vehicles in Table 4.

These targets are inspirational numbers set directly by the DOES working group for the purpose of this analysis. Using these targets, the combined fuel consumption reduction for vehicle fleets under consideration would be 13% (or six million litres) on average for the 3-year scenario. It is important to note that these targets were applied to a small number of military vehicles used in Operation ATHENA. Significant reductions of fuel consumption could be achieved by applying these targets to commercial vehicles used in training and domestic operations.

5.3 Efficiency of legacy platforms

The CF legacy platforms involve transport aircraft, helicopters, naval ships, and armoured vehicles. In contrast with military compounds and ground vehicle fleets, initiatives to improve efficiency of legacy platforms are more complex and would involve disruptive energy technologies. Given that aviation fuel consumptions in expeditionary operations are significant, the analysis focused on initiatives for improving the efficiency of transport aircraft through technology and operational measures. From a technology perspective, given that the efficiency of internal combustion engines of aircraft is generally less than 35% (with most of the energy generated as waste heat), any energy recuperated from the waste heat could be used to improve the energy efficiency of a platform. From an operational perspective, potential reduction of aviation fuel could be achieved through better planning of sustainment flights, fleet mix optimization, increased use of local contracting for general supplies, etc. In this study, the impact of the following examples of targets on aviation fuel consumptions was examined:

1. Improve the energy efficiency of CC-177, CC-130, and CC-150 by 10% through thermal management technologies (e.g., reduce the aircraft fuel consumption rates by 10%).
2. Reduce the number of CC-177 sustainment flights by 10% through better planning of sustainment operations. Historically, a weekly sustainment flight using CC-177 was used for Operation ATHENA.

These targets are also inspirational numbers set directly by the DOES working group for the purpose of this analysis. Using these targets, the combined aviation fuel consumption reduction would be 14% (or 20 million litres) on average for the 3-year scenario.

Table 6 summarizes the analysis of the different target examples and presents the total fuel consumption before and after targets as well as the expected fuel reductions with respect to the baseline scenario. The implementation of these initiatives would generate potential savings of about $33 million from military compounds, $24 million from ground vehicles, and $34 million from legacy platforms during the 3-year scenario. However, a cost-benefit analysis should be undertaken to determine the investments required to implement these targets and the resulting net savings.

Table 6 Fuel consumption before and after targets.

Target Areas	Fuel Consumption (million litres)		
	Baseline	With Targets	Reduction
Military Compounds	55	33	22
Ground Vehicles	45	39	6
Legacy Platforms	140	120	20

6 Conclusions

This paper presents a framework for analyzing fuel requirements for CF expeditionary operations. A fuel consumption prediction model was developed and a generic operational scenario was constructed using historical CF operations to forecast the operational fuel demand. A Monte Carlo simulation framework was also developed to simulate various deployment characteristics. The analysis indicated that the expected fuel consumption for a 3-year scenario in failed and failing states would be 260 million litres (or $408 million). The most prevalent fuel consumption in CF expeditionary operations would be aviation fuel (54%), followed by diesel (38%) and ship's fuel (8%). Given that the analysis was conducted using a generic scenario with different assumptions on operational data and asset characteristics, the fuel consumption results should be interpreted as indicative estimates.

The analysis also revealed that most of the fuel required for expeditionary operations would be consumed during the employment phase (84%). As such, particular attention should be given to this phase for potential fuel consumption optimization. In particular, during the employment phase 40% of the overall fuel consumption would be for aviation fuel, 38% for diesel, and 6% for ship's fuel. The deployment and the redeployment phases account only for 9% and 7%, respectively.

The framework was used to test the impact of different target examples on fuel consumptions for military compounds, ground vehicles, and legacy platforms. The analysis indicated that significant fuel consumption and cost for military compounds (e.g., 40%) could potentially be reduced through various operational initiatives in the short term such as installation of energy efficient structures, use of tactical intelligent power management systems, use of efficient tactical power generator systems, and culture change (this figure is estimated by the model using input data from SMEs). It is also expected that fuel savings in military compounds would reduce the number of convoys in theatre and could be transformed into greater combat efficiency.

Potential fuel consumption reductions for ground vehicles could also be achieved through various efficiency programs such as insertion of energy technologies, incorporation of energy metrics in future acquisition processes, and culture change. Fuel consumption reductions for legacy platforms are more complex and would be achieved in a longer term. Finally, the study indicated that if the scenario involved the deployment of fighter jets, aviation fuel consumption would be much larger. Initiatives to reduce fuel consumption for these aircraft would be through increased used of simulators in trainings, for example.

The study provided insights and better understanding of the fuel consumption patterns for CF expeditionary operations in support of the Canadian DOES development. Future work could include a cost-risk-benefit analysis for implementing different energy measures; analysis of energy consumptions for domestic operations, trainings; as well as an examination of other energy types and contracted lift costs. Another future work direction could also involve the refinement of the model to include sensitivity analysis of the input variables using a gradient vector approach and to indentify those variables that have larger impact on the overall fuel consumption results.

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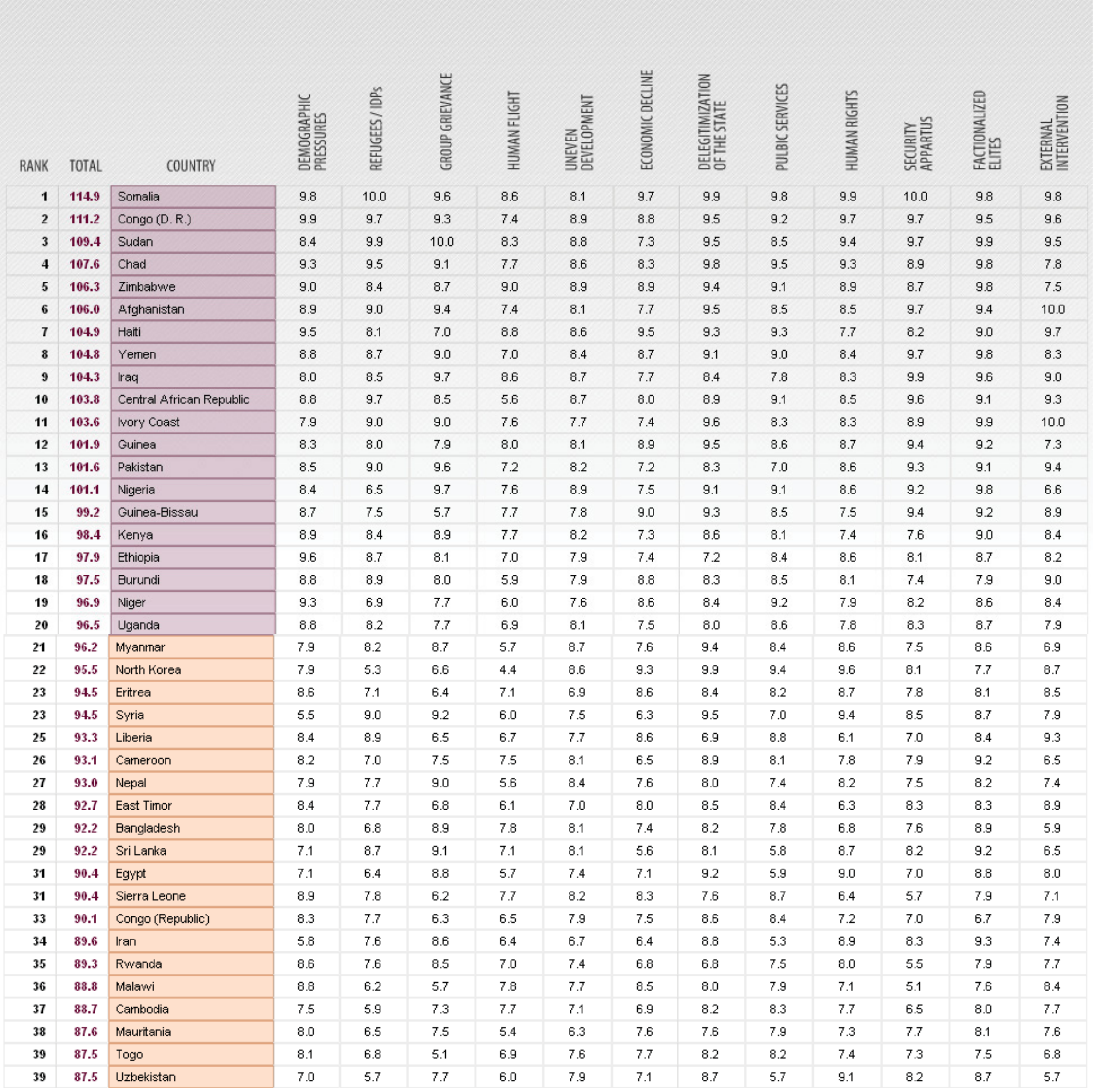
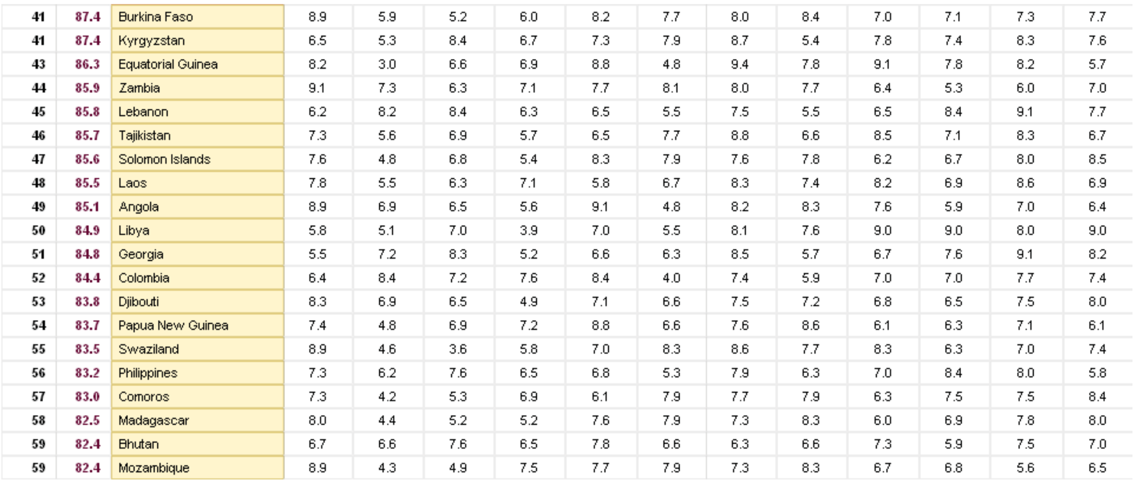
Annex A Failed and Failing States 2012

Annex A presents the list of the top 60 failed and failing states and their characteristics

Table A1. Failed and failing states index, 2012



RANK	TOTAL	COUNTRY	DEMOGRAPHIC PRESSURES	REFUGEES / IDPs	GROUP GRIEVANCE	HUMAN FLIGHT	UNEVEN DEVELOPMENT	ECONOMIC DECLINE	DELEGITIMIZATION OF THE STATE	PULBIC SERVICES	HUMAN RIGHTS	SECURITY APPARTUS	FACTIONALIZED ELITES	EXTERNAL INTERVENTION
1	114.9	Somalia	9.8	10.0	9.6	8.6	8.1	9.7	9.9	9.8	9.9	10.0	9.8	9.8
2	111.2	Congo (D. R.)	9.9	9.7	9.3	7.4	8.9	8.8	9.5	9.2	9.7	9.7	9.5	9.6
3	109.4	Sudan	8.4	9.9	10.0	8.3	8.8	7.3	9.5	8.5	9.4	9.7	9.9	9.5
4	107.6	Chad	9.3	9.5	9.1	7.7	8.6	8.3	9.8	9.5	9.3	8.9	9.8	7.8
5	106.3	Zimbabwe	9.0	8.4	8.7	9.0	8.9	8.9	9.4	9.1	8.9	8.7	9.8	7.5
6	106.0	Afghanistan	8.9	9.0	9.4	7.4	8.1	7.7	9.5	8.5	8.5	9.7	9.4	10.0
7	104.9	Haiti	9.5	8.1	7.0	8.8	8.6	9.5	9.3	9.3	7.7	8.2	9.0	9.7
8	104.8	Yemen	8.8	8.7	9.0	7.0	8.4	8.7	9.1	9.0	8.4	9.7	9.8	8.3
9	104.3	Iraq	8.0	8.5	9.7	8.6	8.7	7.7	8.4	7.8	8.3	9.9	9.6	9.0
10	103.8	Central African Republic	8.8	9.7	8.5	5.6	8.7	8.0	8.9	9.1	8.5	9.6	9.1	9.3
11	103.6	Ivory Coast	7.9	9.0	9.0	7.6	7.7	7.4	9.6	8.3	8.3	8.9	9.9	10.0
12	101.9	Guinea	8.3	8.0	7.9	8.0	8.1	8.9	9.5	8.6	8.7	9.4	9.2	7.3
13	101.6	Pakistan	8.5	9.0	9.6	7.2	8.2	7.2	8.3	7.0	8.6	9.3	9.1	9.4
14	101.1	Nigeria	8.4	6.5	9.7	7.6	8.9	7.5	9.1	9.1	8.6	9.2	9.8	6.6
15	99.2	Guinea-Bissau	8.7	7.5	5.7	7.7	7.8	9.0	9.3	8.5	7.5	9.4	9.2	8.9
16	98.4	Kenya	8.9	8.4	8.9	7.7	8.2	7.3	8.6	8.1	7.4	7.6	9.0	8.4
17	97.9	Ethiopia	9.6	8.7	8.1	7.0	7.9	7.4	7.2	8.4	8.6	8.1	8.7	8.2
18	97.5	Burundi	8.8	8.9	8.0	5.9	7.9	8.8	8.3	8.5	8.1	7.4	7.9	9.0
19	96.9	Niger	9.3	6.9	7.7	6.0	7.6	8.6	8.4	9.2	7.9	8.2	8.6	8.4
20	96.5	Uganda	8.8	8.2	7.7	6.9	8.1	7.5	8.0	8.6	7.8	8.3	8.7	7.9
21	96.2	Myanmar	7.9	8.2	8.7	5.7	8.7	7.6	9.4	8.4	8.6	7.5	8.6	6.9
22	95.5	North Korea	7.9	5.3	6.6	4.4	8.6	9.3	9.9	9.4	9.6	8.1	7.7	8.7
23	94.5	Eritrea	8.6	7.1	6.4	7.1	6.9	8.6	8.4	8.2	8.7	7.8	8.1	8.5
23	94.5	Syria	5.5	9.0	9.2	6.0	7.5	6.3	9.5	7.0	9.4	8.5	8.7	7.9
25	93.3	Liberia	8.4	8.9	6.5	6.7	7.7	8.6	6.9	8.8	6.1	7.0	8.4	9.3
26	93.1	Cameroon	8.2	7.0	7.5	7.5	8.1	6.5	8.9	8.1	7.8	7.9	9.2	6.5
27	93.0	Nepal	7.9	7.7	9.0	5.6	8.4	7.6	8.0	7.4	8.2	7.5	8.2	7.4
28	92.7	East Timor	8.4	7.7	6.8	6.1	7.0	8.0	8.5	8.4	6.3	8.3	8.3	8.9
29	92.2	Bangladesh	8.0	6.8	8.9	7.8	8.1	7.4	8.2	7.8	6.8	7.6	8.9	5.9
29	92.2	Sri Lanka	7.1	8.7	9.1	7.1	8.1	5.6	8.1	5.8	8.7	8.2	9.2	6.5
31	90.4	Egypt	7.1	6.4	8.8	5.7	7.4	7.1	9.2	5.9	9.0	7.0	8.8	8.0
31	90.4	Sierra Leone	8.9	7.8	6.2	7.7	8.2	8.3	7.6	8.7	6.4	5.7	7.9	7.1
33	90.1	Congo (Republic)	8.3	7.7	6.3	6.5	7.9	7.5	8.6	8.4	7.2	7.0	6.7	7.9
34	89.6	Iran	5.8	7.6	8.6	6.4	6.7	6.4	8.8	5.3	8.9	8.3	9.3	7.4
35	89.3	Rwanda	8.6	7.6	8.5	7.0	7.4	6.8	6.8	7.5	8.0	5.5	7.9	7.7
36	88.8	Malawi	8.8	6.2	5.7	7.8	7.7	8.5	8.0	7.9	7.1	5.1	7.6	8.4
37	88.7	Cambodia	7.5	5.9	7.3	7.7	7.1	6.9	8.2	8.3	7.7	6.5	8.0	7.7
38	87.6	Mauritania	8.0	6.5	7.5	5.4	6.3	7.6	7.6	7.9	7.3	7.7	8.1	7.6
39	87.5	Togo	8.1	6.8	5.1	6.9	7.6	7.7	8.2	8.2	7.4	7.3	7.5	6.8
39	87.5	Uzbekistan	7.0	5.7	7.7	6.0	7.9	7.1	8.7	5.7	9.1	8.2	8.7	5.7



41	**87.4**	Burkina Faso	8.9	5.9	5.2	6.0	8.2	7.7	8.0	8.4	7.0	7.1	7.3	7.7
41	**87.4**	Kyrgyzstan	6.5	5.3	8.4	6.7	7.3	7.9	8.7	5.4	7.8	7.4	8.3	7.6
43	**86.3**	Equatorial Guinea	8.2	3.0	6.6	6.9	8.8	4.8	9.4	7.8	9.1	7.8	8.2	5.7
44	**85.9**	Zambia	9.1	7.3	6.3	7.1	7.7	8.1	8.0	7.7	6.4	5.3	6.0	7.0
45	**85.8**	Lebanon	6.2	8.2	8.4	6.3	6.5	5.5	7.5	5.5	6.5	8.4	9.1	7.7
46	**85.7**	Tajikistan	7.3	5.6	6.9	5.7	6.5	7.7	8.8	6.6	8.5	7.1	8.3	6.7
47	**85.6**	Solomon Islands	7.6	4.8	6.8	5.4	8.3	7.9	7.6	7.8	6.2	6.7	8.0	8.5
48	**85.5**	Laos	7.8	5.5	6.3	7.1	5.8	6.7	8.3	7.4	8.2	6.9	8.6	6.9
49	**85.1**	Angola	8.9	6.9	6.5	5.6	9.1	4.8	8.2	8.3	7.6	5.9	7.0	6.4
50	**84.9**	Libya	5.8	5.1	7.0	3.9	7.0	5.5	8.1	7.6	9.0	9.0	8.0	9.0
51	**84.8**	Georgia	5.5	7.2	8.3	5.2	6.6	6.3	8.5	5.7	6.7	7.6	9.1	8.2
52	**84.4**	Colombia	6.4	8.4	7.2	7.6	8.4	4.0	7.4	5.9	7.0	7.0	7.7	7.4
53	**83.8**	Djibouti	8.3	6.9	6.5	4.9	7.1	6.6	7.5	7.2	6.8	6.5	7.5	8.0
54	**83.7**	Papua New Guinea	7.4	4.8	6.9	7.2	8.8	6.6	7.6	8.6	6.1	6.3	7.1	6.1
55	**83.5**	Swaziland	8.9	4.6	3.6	5.8	7.0	8.3	8.6	7.7	8.3	6.3	7.0	7.4
56	**83.2**	Philippines	7.3	6.2	7.6	6.5	6.8	5.3	7.9	6.3	7.0	8.4	8.0	5.8
57	**83.0**	Comoros	7.3	4.2	5.3	6.9	6.1	7.9	7.7	7.9	6.3	7.5	7.5	8.4
58	**82.5**	Madagascar	8.0	4.4	5.2	5.2	7.6	7.9	7.3	8.3	6.0	6.9	7.8	8.0
59	**82.4**	Bhutan	6.7	6.6	7.6	6.5	7.8	6.6	6.3	6.6	7.3	5.9	7.5	7.0
59	**82.4**	Mozambique	8.9	4.3	4.9	7.5	7.7	7.9	7.3	8.3	6.7	6.8	5.6	6.5

Annex B Model Variables

In the model, a number of input variables are represented stochastically to simulate the variations in the operational energy consumption for expeditionary operations. These variables are summarized in Table B1:

Table B1. Model variables and their stochastic variations

System	Variable	Description	Variation (%)
Land	c_v	Fuel consumption rates of ground vehicles	±10
	r_g	Fuel consumption rates of power generators	±10
	d_v	Distance traveled by ground vehicles	±10
	h_g	Daily operating hours of power generators	±10
Air	c	Aircraft fuel consumption rate	±10
	v	Aircraft speed	±10
	x	Helicopter fuel consumption rate	±10
	t	Helicopter flying hours per day	±10
Maritime	S	Number of ships	±10
	y	Ship fuel consumption rate	±10
	q	Number of ship deployment days per period	±10

List of abbreviations/acronyms

AHSVS	Armoured Heavy Support Vehicle System
APOD	Airport of Disembarkation
CAS	Chief of Air Staff
CF	Canadian Forces
CFD	Canadian Force Development
CJOC	Canadian Joint Operations Command
CLS	Chief of Land Staff
CMS	Chief of Maritime Staff
DART	Disaster Assistance Response Team
DND	Department of National Defence
DOES	Defence Operational Energy Strategy
DRDC	Defence Research Development Canada
FBCE	Fully Burdened Cost of Energy
FCU	Fuel Consumption Unit
FCPM	Fuel Consumption Prediction Model
FPS	Force Planning Scenario
ILP	Item Level Prediction
MoD	Ministry of Defence
MLP	Mission Level Prediction
NATO	North Atlantic Treaty Organization
OSH	Operational Support Hub
SPOD	Seaport of Disembarkation
SME	Subject Matter Expert
STANAG	Standard Agreement
UAV	Unmanned Aerial Vehicles
US	United States
VCDS	Vice Chief of Defence Staff

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This paper presents a framework for analyzing the Canadian Forces (CF) operational energy demand. Operational energy is the energy required for training, moving, and sustaining military forces as well as fueling tactical power generators and powering weapons platforms. The study examined the CF operational energy for expeditionary operations and focused particularly on fuel demand. A fuel consumption prediction model was developed and a typical operational scenario was constructed using historical deployments to forecast operational energy demand. A Monte Carlo simulation framework was also developed to simulate various operational characteristics such as location and duration of deployments and fuel consumption rates. The study indicated that the most prevalent fuel consumption in CF expeditionary operations is aviation fuel, followed by fuel for ground systems, and ships. It also revealed that particular attention should be given to the employment phase of operations for potential fuel consumption optimization. The study provided unique insights and better understanding of the energy consumption patterns of CF expeditionary operations in support of the Canadian Defence Operational Energy Strategy development

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Energy, Military, Logistics, Modeling, Fuel

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