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Canadian Forces Overseas Supply Network: Strategic Need and Design Methodology

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Abstract. The Canadian Forces (CF) relies on a supply network to support Canada's international disaster relief, humanitarian assistance, peacekeeping and peace enforcement roles. Internal and external warehousing, maintenance and transportation assets support the deployment, sustainment and redeployment phases of each mission. Currently, this supply network does not incorporate any permanent overseas depots. Since international needs and Canada's roles have significantly evolved during the last decades, and given that supply network efficiency and robustness are critical factors for missions' success, the reengineering of the CF supply network to incorporate permanent international Operations Support Depots (OSD) has become a critical issue. This position paper discusses fundamental factors that may affect Canada's role fulfillment, establishes supply capability needs, and proposes a methodology to design the best overseas supply network for the CF.

Keywords. Canadian Armed Forces, Supply Chain Network Design, Uncertainty, Robustness.

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EXECUTIVE SUMMARY

Canada's current foreign policy includes an effective, appropriate, coordinated and timely response to emergency relief, humanitarian assistance, peacekeeping and peacemaking needs around the world, and this policy is not expected to change in the near future. Foreseeable trends also indicate that the frequency of demands for international aid is likely to increase, and the Canadian Forces (CF) will continue to be a major contributor to these efforts. In the recent past, every year, the CF have been involved in more than ten international missions of different types and size, and this level of involvement is expected to continue.

The deployment and sustainment of overseas missions are complex operations requiring a high level of logistic support. When engaging in an overseas mission, three main time-periods emerge: a deployment phase, a sustainment phase, and a redeployment phase. For any type of mission and for any foreign geographical location in the world, the operational support goals of the CF are:

1. To reduce the deployment period as much as possible while keeping deployment expenses under control (*deployment speed*);
2. To minimize the costs incurred to provide the support level required to ensure that the forces deployed are able to achieve their objectives during the sustainment period (*sustainment efficiency*);
3. To perform an efficient redeployment without undue delays (*redeployment efficiency*);
4. To ensure that the supply network implemented to provide operational support remains fast and efficient, independently of the events that unfold during its intended life, and that it is able to bounce back rapidly from disruptions (*robustness and resilience*).

Providing short deployment times and high sustainment support levels can be extremely expensive, and the CF budgets are limited. This means that a compromise has to be reached. More specifically, adequate tradeoffs between *readiness* investments and operational support costs, and operational support policies specifying maximum deployment period lengths and minimum frequency of carrier visits to operational theatres, must be made. The current Canadian Forces Supply Network (CFSN) involves mainly domestic depots, and it is designed to support overseas missions from Canada. The CF made significant investments recently to upgrade its strategic and tactical airlift capabilities, an important step to improve its ability to deploy quickly from Canada. Despite this, the *status quo* does not seem to be the best possible trade-off between costs and support levels: deployment speed is currently relatively slow, sustainment expenses are high, and the robustness and resilience of the current CFSN are relatively low. It therefore seems that better tradeoffs could be reached.

Several capability options can be considered to improve the global reach of the CF, including: 1) the increase of lift assets capabilities, 3) the dynamic positioning of support ships, 3) the forward prepositioning of selected materiel, 4) the use of standby suppliers for selected materiel, 5) collaborative networking with allies, 6) the improvement of the mission planning process. Given that

Canada is already well engaged in the development of lift assets (option 1) and Joint Support Ships (option 2), and that option 6) pertains to continuous process improvement, the best structural avenue to further improve the capacity of the CF to deploy and employ forces off continent seems to be the implementation of an offshore network of operational support (or prepositioning) depots. The implementation of such a global supply network would build on improvement options 3), 4) and 5). The main logistics roles and characteristics of offshore Operational Support Depots (OSD) would be:

- Depot locations would be a regional logistic hub, have good communication infrastructures, and be in a stable country favourably disposed to Canada.
- Depots would hold an insurance inventory for selected materiel, they would hold cycle and safety stocks during the duration of the missions they support, and they would be able to act as an intermodal transfer point.
- Depots would incorporate a repair shop capable of providing selected 2nd and 3rd line maintenance activities.
- Depots would develop and maintain a local network of external facilities that could be used to support CF activities, and have in place standing offers and contracts with key suppliers, repair facilities and hotels to permit rapid enactment for mission support.
- Depots permanent resources would be kept to a minimum to lower fixed costs, but they would expand as required to handle the throughput of personnel and materiel necessary to support the deployment, employment and redeployment phases of a mission.

It seems likely that an overseas OSD network would improve the CF’s ability to deploy and sustain international missions, and that the savings obtained by avoiding unnecessary lift costs would outweigh added fixed and variable costs. Additional savings would come from the local procurement of some materiel to avoid shipments from Canada, and the local repair of equipments to avoid backhauling costs to Canada. This seems even more obvious when considering the current increasing fuel cost trend. Moreover, such a global supply network would be much more reliable and resilient than the current CFSN based on two Canadian supply depots.

The strategic decisions to design such an overseas supply network for the CF are the following:

1) the number of offshore OSDs to implement, their location and their capacity (in terms of warehousing and repair);
2) the OSD location from which to support missions occurring in the various countries of the world;
3) the amount of insurance inventory to keep in each OSD, for all selected product families;
4) the operational support policy to implement for each mission type and geographical region.

This network design problem is complex because it involves numerous conflicting objectives and because potential networks must be evaluated without knowing the missions the CF will have to support in the future. For example, when the number of OSD implemented is increased, the transportation costs are expected to go down, the deployment period to decrease, the frequency of theatre replenishments to increase and the robustness of the network to improve, all of which is positive. However, the facilities investment and operating costs, as well as the inventory holding costs are expected to increase, which is certainly not desirable. What are the best tradeoffs? It is not easy to answer this question, mainly under uncertainty. Providing an adequate answer requires the use of a relatively sophisticated risk assessment and decision methodology.

The approach proposed to answer the questions raised in the previous paragraphs is based on the generic supply network design methodology developed by the DRESNET (Design of Robust and Effective Supply Network Engineering Tools) team at *Université Laval*. The methodology is essentially composed of three phases: scenario generation, design generation and design evaluation. The first phase is a Monte Carlo scenario generation procedure. Each scenario covers a complete planning horizon (say 10 years) and it details all the missions of different types performed in different countries during this period, as well as all the extreme events occurring at the OSD locations. It also specifies demand and repair profiles by product families for each weekly period during each mission. The design generation phase uses an optimization model to find the supply network structure providing the best cost-service tradeoffs, for a sample of scenarios. In order to obtain different candidate designs, this model is run several times with different samples of scenarios. The design evaluation phase then compares the candidate designs with the *status quo* design. This comparison is based on the optimal planning and control decisions made by the network users for the design considered under a large sample of scenario. These lot-sizing, transportation and repair scheduling decisions are made using a relatively detailed user model. Additional metrics can also be used to evaluate a design, and the evaluation can be performed for worst-case scenarios. Comparisons are based on expected values, but also on selected dispersion measures to evaluate robustness. Based on all these multi-criteria evaluations, the candidate designs can be ranked, and a *best* design can be selected.

In order to demonstrate that this methodology can indeed be applied to the CF context, and is likely to provide a superior supply network design, it should first be tested on a realistic but fictitious case built to be as close as possible to the real CF overseas network context. Once this proof of concept done, the best avenue would be to develop a generic computer aided design tool to facilitate the application of the methodology, and to use it to solve the real CF case. This tool could subsequently be employed by the Canadian Operational Support Command (CANOSCOM) to continuously improve its supply network as needs evolve and as the international and national context change.

1 INTRODUCTION

The Canadian Forces (CF) role in today's world has greatly evolved since World War II. It has stretched both from a geographic and mission spectrum's points of view, which pressures the CF Supply Network (CFSN) managed by the Canadian Operation Support Command (CANOSCOM). At the beginning of the 1990s, the CFSN was redesigned as a hub and spoke network giving a central role to two hubs: the Edmonton and Montreal CF Supply Depots (CFSD). This supply network must currently support both domestic and overseas missions. Compared to the mid-20th century major conflicts involving the CF, which occurred mainly in Europe and in its vicinity, today's operations are spread throughout the entire world. South-America, Africa, the Middle-East and Asia are all potential regions for tomorrow's CF operations. Moreover, the CF are currently asked to respond to disaster relief, humanitarian assistance, peacekeeping and peace enforcement missions, and future operations are likely to involve several of these mission types at once. While the domestic CFSN has been redesigned and is now considered fixed to a certain extent, its overseas counterpart is a major subject of concern for CANOSCOM. Currently, the CF overseas supply network uses mainly third party facilities and transportation assets. This leads to a double consequence: the absence of overseas depots imposes a direct supply from Canada mainly via airlifts, and the lack of transportation assets imposes the use of costly and constrained chartered lifts. A major issue is to determine what proper mix of overseas depots and transportation assets would increase the CF responsiveness and efficiency during the deployment, sustainment, and redeployment of overseas missions.

The objective of this position paper is to address this issue by stressing the strategic needs of the Forces at that level, proposing capability goals for a multinational CFSN and proposing an approach to design a robust and efficient international prepositioning supply network. The paper is divided into five parts. The first part gives an overview of international conflict and disaster trends, and of Canada's international roles, that might generate overseas missions for the CF. The second part identifies overseas missions deployment and sustainment requirements. The third part establishes the strategic need for an international CFSN by examining the current CF supply network and by identifying capability gaps. The fourth part examines the possibility of implementing an overseas Operational Support Depot (OSD) network. It underlines capability goals that should guide future overseas CFSN structural changes. Finally, the last part proposes a supply network engineering approach. It describes network elements and design objectives that should be considered in order to meet strategic needs and capability goals.

2 CANADA'S INTERNATIONAL ENGAGEMENTS EVOLUTIONARY TRENDS

In order to appreciate the logistic capabilities required to support CF operations outside Canada, it is necessary to review the trends related to Canada's international engagements that might generate overseas missions. Through its engagements with the United Nations (UN) and the North Atlantic Treaty Organization (NATO), Canada is likely to be involved in three types of mission: emergency relief and humanitarian assistance, peacekeeping, and peace enforcement (peacemaking). In emergency relief missions, the supply network's critical role is the "coordination of all activities required to minimize the response time and to maximize the relief in a disaster zone" (Tovia, 2007). Humanitarian disaster relief operations can last from a few weeks to several years (Beamon and Kotleba, 2006), but the military involvement usually does not last more than a few months. Peacekeeping missions are understood as "legitimized interventions aimed at avoiding the outbreak or resurgence of violent conflict between disputants", they are non-threatening and impartial (Berdal, 1993). Peace enforcement missions cover a large spectrum of violent interventions considered as morally necessary according to the concept of "just war" (Waltzer, 2005). Peacekeeping and peace enforcement missions are legitimized under Chapters 6 and 7 of the UN Charter. This section provides an analysis of international trends related to these three types of missions, and examines Canada's foreign policies that might lead to CF overseas operations.

2.1 Armed Conflicts

An analysis of modern conflicts leads to the observation "that the overwhelming majority of conflicts since the end of World War II have been located in the Third World" (Ayoob, 2001). The snapshot for year 2004 provided in Figure 1 substantiates this assertion. Figure 2 shows how the conflicts in the world have more than tripled since 1945 and, sadly, it seems likely that this trend will continue.

Nowadays armed conflicts have changed noticeably and the international community tries to adapt its response model: "conventional concerns about superpower confrontation, the balance of power, alliances, arms races, and deterrence have given way to new concerns about regional conflicts, ethnonational wars, religious militancy, resource scarcity and environmental degradation, preventive diplomacy, peacekeeping, and humanitarian intervention" (Levy, 2001). In recent years, domestic problems and international order have started to intertwine more closely: the international community is now a major player in many local conflicts. Passivity when observing mass killings is now severely criticized by an increasing part of the Western population, which tends to legitimize interventionism, usually under the UN umbrella. Since the beginning of the 1990's, the UN has started to override domestic sovereignty, and the interpretation of the motives for interventions has widened, the only effective judge being the Security Council (*ibid*).

Each year, Foreign Policy and the Fund for Peace evaluate a *Failed and Failing States Index* for the different countries of the world. These indexes are shown in Figure 3 for the year 2008. The evaluation of each country's index is based on 12 economical, political, social and ethnic indicators detailed on the Fund for Peace Web site (www.fundforpeace.org). For *failed states*, it "can be demonstrated that in the absence of even rudimentarily effective states to provide a minimum degree of political order – as in Lebanon for the fifteen years of civil war, or as currently in Somalia, Liberia, or Sierra Leone, to mention just a few examples – the concept of human rights remains nothing more than a pure abstraction" (Ayoob, 2001). Consequently, a significant part of international interventions are occurring in *failed states*. Conflicts can also be caused by the scarcity of world resources (Le Billon, 2005). Examples linking war with petrol, diamonds and drugs are numerous. In particular, the accentuated scarcity of water is expected to be the source of numerous future conflicts (Beschorner, 1992).

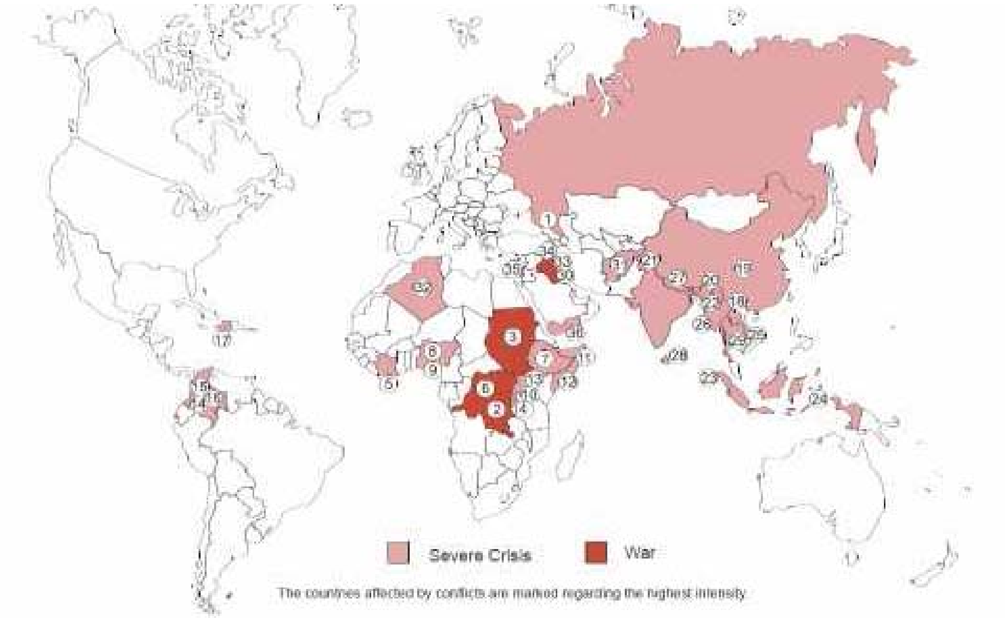

Figure 1. *Violent Conflicts of High Intensity in the World in 2004*[1]

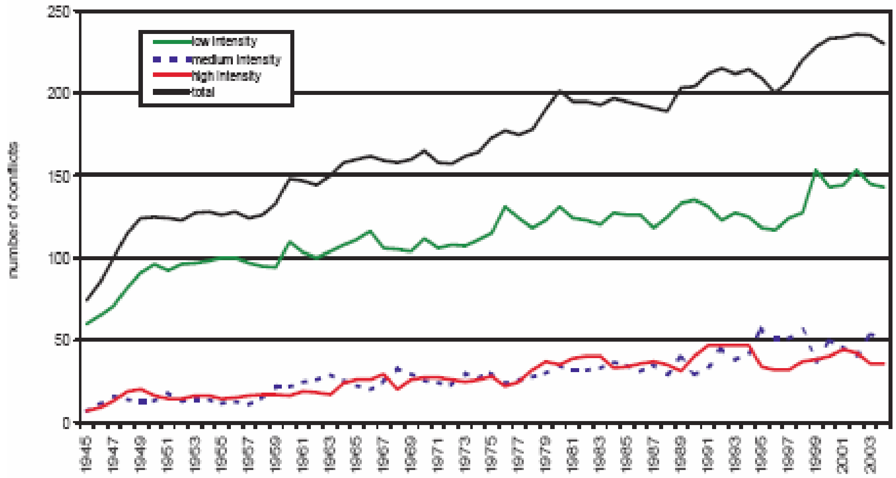

Figure 2. *Evolution of Conflicts in the World (1945 to 2004)*[2]

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[1] Source: Hélène Lavoix, 2006 (http://www.cedoc.defense.gouv.fr/IMG/pdf/previsionconflitAFDHL1.pdf)

[2] *Ibid*.

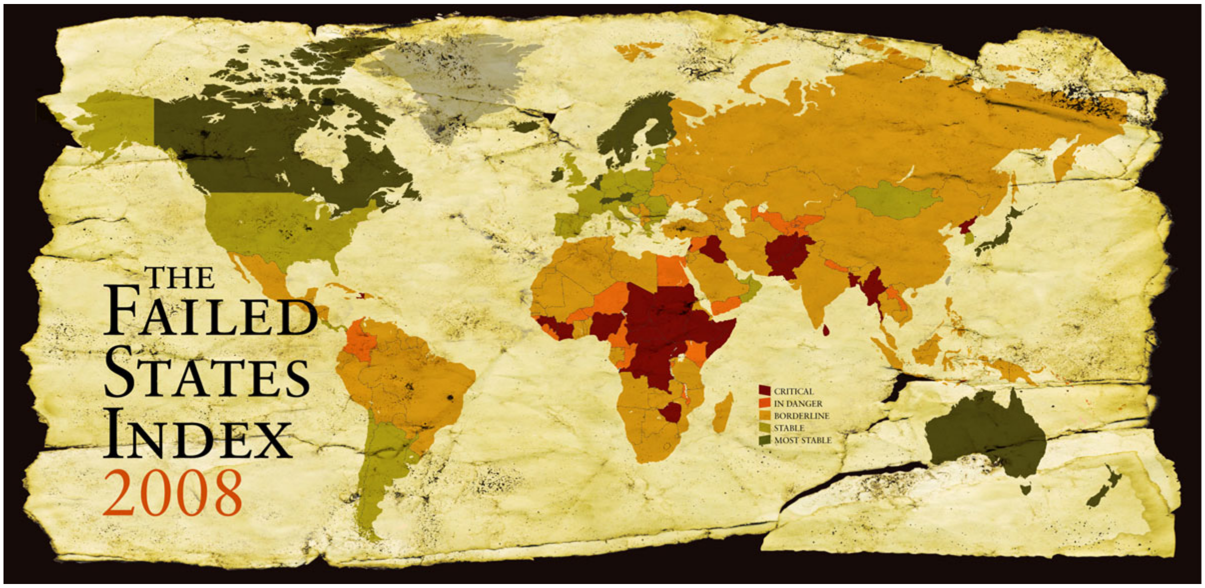

Figure 3. *World Map of the Failed States Index 2008*[3]

2.2 Humanitarian Relief

With modern information and communication networks, people anywhere on the planet are rapidly informed of natural disasters and humanitarian crisis, and there is an increased pressure on the governments of developed countries to provide efficient international aid. The word *natural disaster* refers to the occurrence of severe natural phenomena such as earthquakes, tsunamis, volcanic eruptions, hurricanes, floods and landslides (Cardona, 2004). The *Centre for Research on Epidemiological Disasters* (CRED) in Belgium collects data on the natural hazards that occurred since the beginning of the 20th century. Statistics on the number of people killed by natural hazards since 1980 are presented in Figure 4. Note that the *Complex Disasters* category used by CRED incorporates armed conflicts such as the Rwanda genocide, which is somewhat misleading. However, it is interesting to observe that these *Complex Disasters* are responsible for the largest number of death.

It should be realized that natural disasters are complex phenomena, and that they cannot be understood without taking account of social vulnerabilities. “Whereas disasters used to be practically equated to natural hazards, they now became understood as the interaction between hazard and vulnerability” (Hilhorst, 2004). From this point of view, natural disasters occurring in socially vulnerable regions may generate much more severe disasters (Oliver-Smith, 2004), requiring humanitarian assistance over a significant time-period. For example, a natural disaster may lead to starvation and malnutrition.

Along with natural disasters, food scarcity is one of the most important risks that the world community will have to face for the next decades. “Food security, at the nexus of a number of issues from energy security to climate change and water scarcity, may be emerging as one of the major

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[3] Source: Foreign Policy (http://www.foreignpolicy.com/story/cms.php?story_id=4350)

risks of the 21st century. Long- and short-term drivers – population growth, changing lifestyles, climate change and the growing use of food crops for biofuels – may be shifting the world into a period of more volatile and sustained high prices. The consequences, particularly for the most vulnerable communities, may be harsh" (World Economic Forum, 2008). As it was the case for armed conflicts, this major humanitarian disaster risk mainly appears in the undeveloped countries.

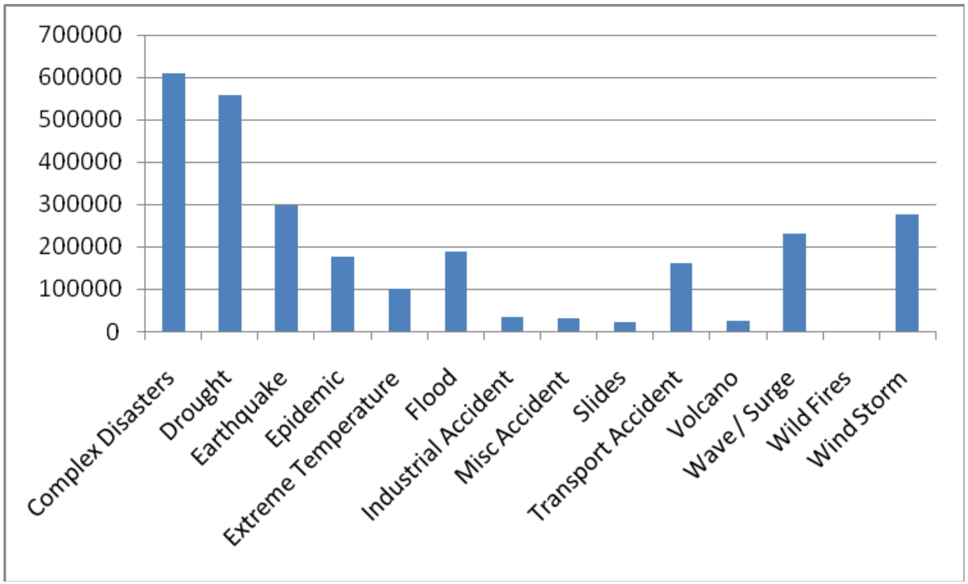

Figure 4. *Number of People Killed by Natural Hazard (1980 to 2006)*[4]

Finally, another type of emergency relief need occurs when Canadian citizens abroad are in danger. For example, between July 19th and August 15th 2006, the CF evacuated 40,000 non-combatant Canadians from Lebanon. Following most conflict, there is also a need humanitarian intervention such as Nation rebuilding, aid to civil power and mine actions.

All these needs have resulted in the development of emergency-relief organization networks. These networks involve Non Governmental Organizations (NGOs) such as the Red Cross, *Médecins Sans Frontières* (MSF), CARE and OXFAM, as well as governmental organizations such as the Stabilization and Reconstruction Task Force (START) in Canada, but they rely heavily on military forces support. One of their aims is to setup emergency logistics networks to bring relief quickly and efficiently to natural and human-made crises that require coordinated action. Previous studies on such networks "show that even if there has been improvement in evacuation and emergency preparedness systems, it is apparent that with the current resources and operating policies the emergency management offices are not achieving their objectives. Even more, the cited researches show that no increased transportation or road building would allow evacuating the population in a timely manner" (Tovia, 2007). The road ahead is therefore quite challenging.

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[4] Source: Centre for Research on Epidemiological Disasters (CRED) www.cred.be (2007)

2.3 Canada's Foreign Policies and Engagements

As a developed country, Canada belongs to a group of states promoting a sense of international community through foreign aid and internationally supported military engagements. When witnessing violent and massive human rights violations, or catastrophic natural disasters, somewhere on the planet, these countries are solicited to intervene, and they must be prepared to do so (Hoffmann, 2001). These interventions can take several forms: "All too often, the intervention debate has been handled as if the only real issue is military intervention, as distinguished from other types of third-party-assisted processes by a range of 'external' actors" (Crocker, 2001). Nowadays, the term "intervention" reaches a full spectrum of methods and tools employed by a variety of players: countries, the UN, and NGOs, in military and non-military contexts.

Canada has taken a leadership role in supporting conflict and disaster-affected populations. Canada is typically among the first countries to respond to requests for international emergency relief, peacekeeping or peacemaking aid. Canada has participated in operations led by the UN, NATO, the European Union (EU), and the African Union (AU), with the objective to provide security, stability, and a spectrum of support to needing populations. Canada's current foreign policy is to ensure an effective, appropriate, coordinated and timely response to humanitarian and peacekeeping needs abroad, and this policy is not expected to change in the near future. This "reflects our values and principles, and responds directly to our national interests in promoting peace and security, prosperity and well-being around the world" (Department of Foreign Affairs and International Trades - www.international.gc.ca).

As indicated in this section, because of the social changes prompted by the global economy, scarcity of resources and increased environmental pressures, armed conflicts and serious humanitarian crisis are expected to increase in the future. A recent Defence R&D Canada (DRDC) study (Mason and Dickson, 2007) concurs with this assessment and adds that a higher percentage of missions are expected to be combat missions. Given Canada's engagement to be an important contributor to the solution of emerging international conflicts and crisis, it is clear that this will put additional stress on the Forces and resources allocated by Canada to these missions. The Canadian Armed Forces are not the only Canadian organisation involved in these missions but they provide a major contribution. Also due to technological opportunities and governance pressures toward efficiency, the strategic and operational management of supply networks will likely be subject to drastic changes. A dominant paradigm driving perspectives on future military missions is the *Three Block War* (also called full spectrum operations) which argues that a deployed force should be able to manage, at a same time and in the same region, peace enforcement (combat) and peacekeeping (stabilization) missions, as well as a humanitarian assistance operation (Krulak, 1999). For developed countries such as Canada, this implies that major changes to military supply chains will be required to support 21st century missions.

3 CF INTERNATIONAL MISSIONS REQUIREMENTS AND GOALS

Our previous discussion stressed that Canada will continue to intervene in emergency relief, peacekeeping and peacemaking missions around the world and that foreseeable trends indicate that the frequency of demands for international aid is likely to increase. It also seems likely that the Canadian Armed Forces will continue to be a major contributor to these missions. Our aim in this section is to examine more closely the nature of the CF missions abroad, and to identify clearly the supply capabilities that will be required to support these missions in the future.

3.1 Missions Life Cycle and Operational Support Requirements

Mason and Dickson (2007) compiled the major CF operations from 1990 to 2004. A schema of these missions appears in Figure 5. Four key mission dimensions are represented: time, location, size of the CF contribution (depicted by the bar height), and type. It is clear from this figure that, compared to domestic operations, overseas missions represent a noticeable part of the CF engagements, and that nowadays CF logistics support needs are geographically dispersed. It is also notable that the CF engages in several types of missions, but that the peace support operations are the most common. Based on the list of missions in Figure 5, between 1990 and 2004, each year the Canadian Forces have been involved in an average of 13 international missions of different types. Some of these missions are quite small and they involve only a few persons. Statistics on average mission duration, personnel deployed and mean time between missions are provided in Table 1.

Region	Mission Type	Average Duration [months]	Average Number of Personnel Deployed	Mean Time Between Missions [months]
Africa	HI	5.0	168	32.6
	PK	45.3	241	21.2
Americas	HI*	2.0	313	—
	PK	33.0	427	84.5
Asia	HI	13.0	131	—
	PE	13.5	1 061	—
	PK	48.6	489	30.8
Europe	HI	23.3	709	28.3
	PE*	32.0	150	-
	PK	20.6	199	44.3

HI: Humanitarian Intervention PK: Peacekeeping PE: Peace Enforcement

* Based on a single observation — Not enough observations to compute the mean

Table 1. *CF Mission Statistics*[5]

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[5] Calculated from the data provided in Annex F of Mason and Dickson (2007). Note that this data excludes naval ship deployments. Note also that the statistics refect avarege values by operations and that missions involving less than 20 persons were removed from the sample.

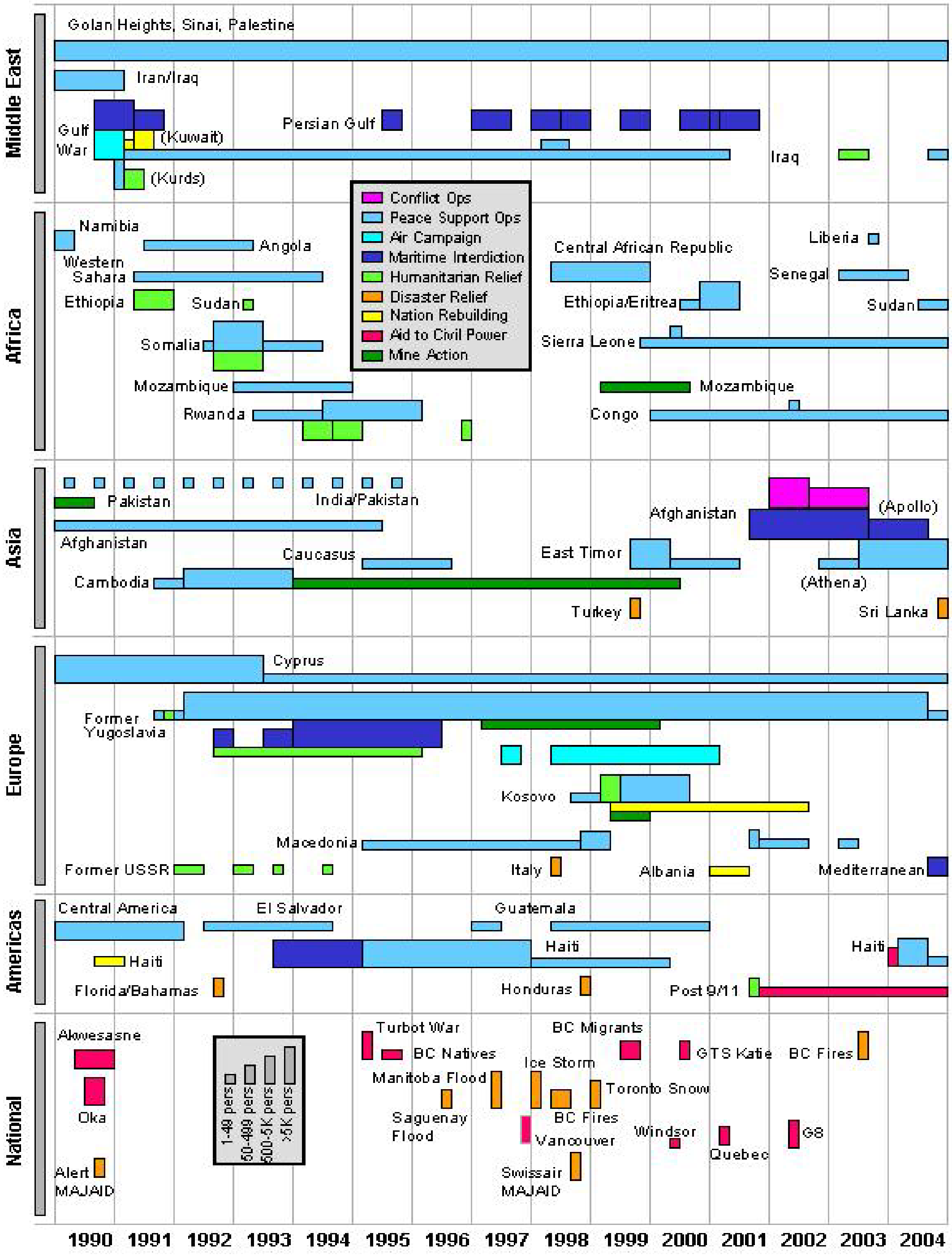

Figure 5. *Canadian Forces Major Operations (1990-2004)*[6]

The geographical dispersion of military operations and the large variety of mission types encountered generate in turn a wider spectrum of operations *intensity*. The intensity of a mission depends on its *severity* and on its *magnitude* (size). Magnitude is measured in terms of the number of personnel deployed. A convenient measure of magnitude, in a land operations context, is the

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[6] Source: Mason and Dickson (2007)

number of companies deployed plus the fixed personnel required for services such as command (National Command Element), logistics (National Support Element), maintenance and medical support. The number of companies deployed depends on the engagements taken by Canada in the context of a specific mission. Severity is related more to the nature of the mission itself. It can be characterized in terms of *hostility* and *hardship*. Hostility reflects the level of aggressiveness of enemy forces (threat level). Hardship is related to the physical nature of the theatre terrain. The Department on Hardship and Hostility evaluates a mission's severity during the Operation Planning Process (OPP), taking account of host nation support capability and inputs. The logistic support required is clearly directly proportional to the intensity of a mission.

Each mission incorporates several phases. Table 2 presents a description of the standard mission phases recognized in the CF. During the *Warning* phase, the CF gathers information on the operation's theatre and elaborates scenarios and plans to meet the objectives. The *Preparation* phase starts when the Government gives a go to the mission. Depending on the mission, units may train before they leave and a Theatre Activation Team (TAT) may deploy to ensure that the incoming troops will find proper shelter and basic commodities when they arrive. Some heavy equipment may also be transported in advance. During the *Deployment* phase, units and their equipment are moved from their base for a tour of duty. The *Employment* (or sustainment) is the main phase of the mission. Personal rotations are required for missions lasting more than 6 months. The supply's job during this phase is to support rotations and to resupply the goods consumed during the mission. Some equipment may also be repaired in theatre maintenance facilities, or shipped back for repair or overhauling, and new equipment may be brought in. The *Redeployment* phase occurs when the mission is over.

Mission Phase	Description
Warning	Government asks for analysis of the potential operations profile.
Preparation	Units train for the mission's objectives according to the projected conditions. Theatre Activation Team (TAT) deploys to prepare the full deployment of the mission. Some heavy equipment is deployed.
Deployment	Units and their equipments are deployed.
Employment	The mission is sustained from Canada and local suppliers through the National Support Element (NSE).
Redeployment	All units and their equipments are moved back to Canada, sold, given, or disposed.

Table 2. *Standard CF Mission Phases*

The actual timing of these phases can vary depending on the mission type. For example, DART (Disaster Assistance Response Team) missions arise virtually without warning, and there may be only a few days between the warning and the employment phases. For recent DART missions in response to major natural disasters, the actual preparation and deployment time has rarely been less than 6 days, which is relatively long considering the fact that people rarely survive if not recued within 72 hours. For other humanitarian crisis such as famine and extensive refugee movements, deployed CF units were operational between 7 and 19 days after the warning phase (Mason and Dickson, 2007). On the other hand, more than a month can be required for the deployment of a mission engaging a full battle group in a land-locked theatre.

Several factors may complicate the preparation and deployment phases of a mission. Few deployments occur adjacent to large airports and/or deep-water seaports. Missions often occur in locations where infrastructures are poor or non-existent. This usually leads to the use of an Intermediate Staging Base (ISB) in a close-by location with adequate airport and seaport. Implementing such a two-echelon supply chain is relatively simple when the ISB can be located in a NATO country. By contrast, the arrangements to find and setup a suitable ISB in non-NATO countries can be far more difficult and demanding (Boomer, 2006). Furthermore, deployment constraints often result from the fact that several countries and support organizations may be deploying simultaneously to the theatre of operation. For example, this may seriously limit the number of landing time-slots per day available at the destination airfields. This type of constraint may significantly prolong the time required to complete a deployment (Boomer, 2006).

The ability to move efficiently equipment, supplies and personnel to, from and within a theatre of operations is a critical success factor. Options available to move equipment and supplies may include ground, sea, and air transportation. Since Canada is the second largest country in the world and comprises many large remote areas, transport by air is usually the first option considered, especially when long distances are involved. Transport by air and sea are the two options available when materiel and forces must be moved overseas. The transport of personnel, equipment and cargo by air involves the use of aircrafts that perform two distinct functions: inter-theatre airlift (strategic airlift) and intra-theatre airlift (tactical airlift). Strategic inter-theatre airlift involves transport to, from and between supply sources and theatres of operation. Tactical intra-theatre airlift involves transport within theatres of operation. The airlift operations are subject to a number of constraints: airspace access, airfield access, airfield operations, and airspace restrictions.

During the deployment, employment and redeployment phases, the CF must move thousands of products. These products can be classified into three main types: consumable, repairable and durable items, the later being major equipments, which need to be maintained. These products are moved in units (i.e. as is), in pallets, in refrigerated containers, or in non-refrigerated containers. Table 3 summarizes the standard classes of supply used by both the Canadian and US Forces. From a transportation needs point of view, the products can be partitioned into five broad categories: ammunition, major items, dangerous, refrigerated cargo, and non-refrigerated cargo. Some of these product categories cannot be mixed in the same shipment, which complicates transportation planning. Table 4 partition supply classes into 11 Product Families according to product categories and shipping units. It should be noticed that *outsized* cargo is defined as a major item that, because of length, width, height and/or weight, cannot fit into a Hercules-sized aircraft. Such cargo includes equipment such as the HLVW vehicle used by DART.

In order to deploy for a mission, the supplies, equipment and troupes to move to the theatre must be available when the mission starts, and the transportation assets required to move them must also be available. Since we do not know exactly when a mission will arise, a certain amount of *insurance* inventory (mainly for consumable and reparable materiel, but also for some durable items) must be kept in anticipation of future deployment needs. If the required materiel is not available, serious deployment delays can be incurred. On the other hand, keeping an excessively high insurance inventory is very expensive; both from the point of view of the capital immobilized and of the warehousing facilities required for its storage. This implies that a proper balance between *readiness* and inventory investments must be reached. A similar trade-off must be made for transportation assets: if the required planes and ships are not available when needed, serious delays may be incurred. In both cases, if the level of resources available is insufficient, recourse actions are possible. Some materiel can be procured from external suppliers and some transportation assets can be leased, but this requires time and it may be very expensive.

No	Title	Description
I	Subsistence	Food, rations, and water
II	Clothing & Individual equipment	Clothing, individual equipment, tentage, organizational tool sets and tool kits, hand tools, maps, and administrative and housekeeping supplies and equipment
III	POL	Petroleum fuels; lubricants; hydraulic and insulating oils; preservatives; liquid and compressed gasses; bulk chemical products; coolants; deicing and antifreeze compounds, together with components and additives of such products; and coal
IV	Fortification and barrier materials	Construction materials, including installed equipment and all fortification/barrier materials
V	Ammunition	Ammunition of all types, including chemical and special weapons, bombs, explosives, mines, fuses, detonators, pyrotechnics, missiles, rockets, propellants, and other associated items.
VI	Personal Items	Personal demand items (nonmilitary sales items).
VII	Major End Items	Major end items: a final combination of end products that are ready for their intended use, for example, tanks, launchers, mobile machine shops, and vehicles.
VIII	Medical supplies	Medical materiel, including medical-peculiar repair parts.
IX	Repair Parts	Repair parts (less medical-peculiar repair parts): all repair parts and components, to include kits, assemblies, and subassemblies—repairable and non-repairable—required for maintenance support of all equipment.
X	Miscellaneous	Materiel to support nonmilitary programs, such as agricultural economic development, not included in Classes I through IX.

Table 3. *Canadian and US Standard Supply Classes*[7]

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[7] Source: www.globalsecurity.org

Category	Type	Shipping Unit			
		Unit	Pallet	Refrigerated Container	Container (non-refrigerated)
Ammunition	Consumable		1) V		
Major Items	Durable	2) VII			3) VII
Outsized Items	Durable	4) VII			
Dangerous	Consumable				5) III
Cargo (refrigerated)	Consumable			6) I, VIII	
Cargo (non-refrigerated)	Durable	7) IV, X			
	Consumable		8) I, II, IV, VI, VIII		9) I, II, IV, VI, VIII
	Repairable		10) II, IV, VIII, IX		11) II, IV, VIII, IX

Table 4. *Partition of Supply Classes into Product Families*

3.2 International Missions Operational Support Goals

From an operational support point of view, when considering the time axis, three main time-periods emerge:

- *deployment phase*, which starts when the decision to intervene is made and finishes when all the materiel required to support the troops has arrived at the operations theatre (this period covers the preparation and the deployment phases defined in Table 2);
- *sustainment phase*, which lasts until the mission objectives have been reached;
- *redeployment phase*, which finishes when all equipment and supplies have been brought back, sold, given or disposed.

For any type of mission and for any foreign geographical location in the world, it can be stated that the operational support goals are:

1. *Deployment speed*: to reduce the deployment time as much as possible while keeping deployment expenses under control;
2. *Sustainment efficiency*: to minimize the costs incurred to provide the support level required to ensure that the forces deployed are able to achieve their objectives during the sustainment period;
3. *Redeployment efficiency*: to perform an efficient redeployment without undue delays;
4. *Robustness and resilience*: to ensure that the supply network implemented to provide operational support remains fast and efficient, independently of the events that unfold during its intended life, and that it is able to bounce back rapidly from disruptions.

Providing very short deployment times and very high sustainment support levels can be extremely expensive and the CF budgets are limited. This means that in practice, a compromise has to be reached. Two types of expenses must be distinguished: *readiness* investments and expenditures, and operational support costs. Readiness investments and expenditures are usually made beforehand, to ensure that high service levels will be provided when the need arises. They include investments in insurance inventory, the ongoing costs of operating depots to stock these inventories, the investments costs required to set-up adequate equipment repair units, and the investments, maintenance and operating costs required to operate transportation fleets. They are typically related to supply network design variables such as the number, capacity and location of depots to operate, the amount of insurance inventory to keep in different locations and the internal transportation capacity to invest in. The operational support costs are related to the support of individual missions. They are associated to supply, maintenance and recourse actions taken during the mission, such as the usage of the internal transportation fleet and of for-hire carriers to deliver products to the theatre. These two expense types are constrained by different expenditure control mechanisms.

In order to reach a proper compromise between service levels and expenditures, some operational support policies must be elaborated, either implicitly or explicitly. These policies normally depend on the type of mission and on the geographical region where the mission occurs. Some of these policies specify maximum deployment period lengths. Others specify a minimum frequency of carrier visits (or minimum weekly reception/shipping capacity) at the theatre port of debarkation/embarkation. For a policy to be feasible, it must be supported by a capable strategic line of communication (SLOC), based on adequate sourcing points, transportation assets, intermediate staging point port infrastructures, warehousing facilities and repair facilities. A policy can be implemented only if the cost of these resources is not prohibitive. In other words, for a given budget, the operational support design problem is not only to find the best resource deployment, but also to find the best support policies to implement.

Finally, the supply network designed to support international missions must be robust, i.e. it must be able to provide superior deployment speed and sustainment efficiency, independently of the events that unfold during its intended life. These events refer obviously to the portfolio of international missions it has to support during its life, but also to events that may affect its own structure and performance. Even if the supply network warehouses and transportation assets are not based on operational theatres, their operation may be perturbed by accidental, natural or wilful hazards such as fires, labour disputes, natural catastrophes (hurricanes, earthquakes, floods…), power breakdowns and terrorist attacks. To make sure that the supply network designed is resilient, that is that it can bounce back easily when such disruptions occur, it must allow some back-up mechanism that preserve the quality of service without adding excessive costs.

4 CURRENT CANADIAN ARMED FORCES SUPPLY NETWORK

The CF supply network spans from its vendors to the overseas theatre of operations, moving thousands of products daily, and keeping them in inventory for various needs (insurance, security, or cyclic inventories). In this section, we provide an overview of the current CFSN and of the transportation assets owned by the CF. We then examine the third parties' transportation assets used by the CF. After this overview of the current CF international supply network, we identify some capability gaps.

The CF organization responsible to provide operational support to Force elements is the Canadian Operational Support Command (CANOSCOM). CANOSCOM supports all Canadian Forces domestic, continental and international operations. Its first task is to generate task-tailored operational support organizations for the new operational commands – Canada Command (Canada COM), Canadian Expeditionary Force Command (CEFCOM) and Canadian Special Forces Command (CANSOFCOM). CANOSCOM is responsible for planning and executing the delivery of national-level operational support for theatre activation, sustainment and termination of a CF operation. CANOSCOM covers a full range of combat service functions, including aspects of military engineering, health services, military police, logistics, land equipment maintenance, personnel support, resource management, and communications and information systems. Evolving through a recently designed organizational structure and new business processes emerging from Force transformation, key CANOSCOM decision-makers currently exploit a variety of distributed multi-level data/information sources, information systems and decision support technologies to carry out logistic tasks.

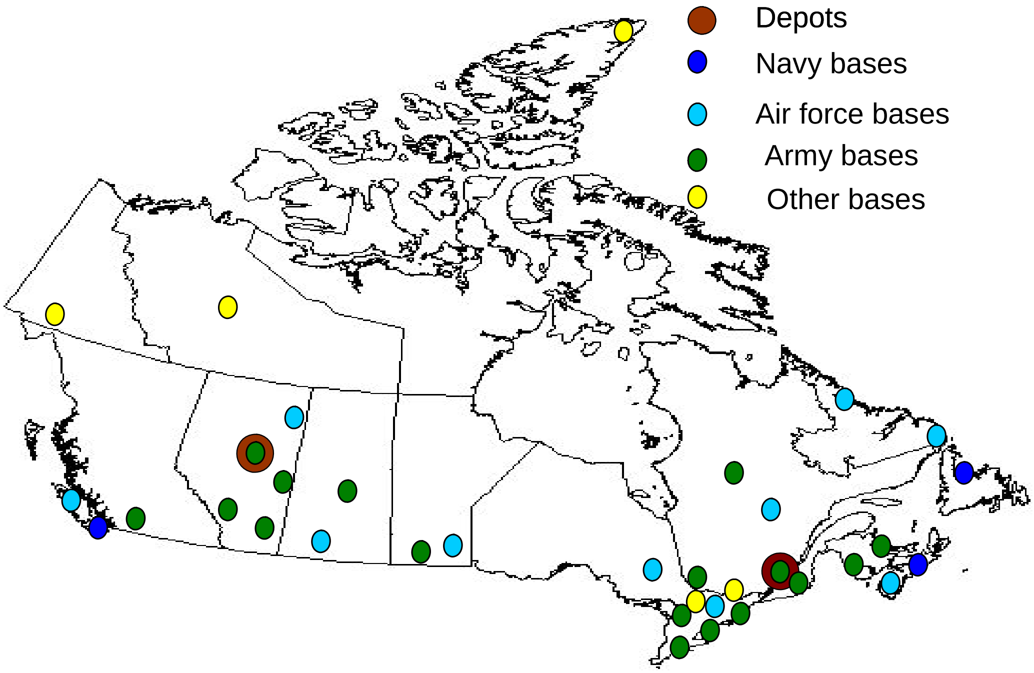

Figure 6. *The Different Bases of the CF Supply Network*

4.1 Current CF Supply Network Overview

Figure 6 presents a map of the domestic CFSN. Two CF *supply depots* receive, store and distribute nationally managed materiel procured by DND. The materiel not needed by customers is returned to the supply depots for possible redistribution to other users. These depots are located in Montreal and Edmonton. They are organized to respond to their particular requirements, however, the two depots perform the same functions. Two other smaller supply depots are located in Halifax and Esquimalt, and four ammunition depots are located in Victoria, Dundurn, Borden and Halifax. Most of the inbound flows to the supply depots come from commercial suppliers and a smaller portion are returns from bases. Materiel is stored at multiple locations and in multiple tiers across the CF supply network. It is distributed and moved along multiple lanes, mainly in-between supply depots, between depots and bases and, on an ad hoc basis, between bases. The current network was designed by the Material Acquisition and Supply Optimization Project (MASOP) team, and it has a Hub and Spoke structure.

Currently, all international missions are also supplied from these domestic depots. The main ports of embarkation for overseas missions are Trenton airport for airlift and Montreal harbour for sealift. From an equipment maintenance, modification and overhauling point of view, most CF bases have their own maintenance units. Basic repairs (2nd line maintenance) are done locally, but major repairs and overhauls (3rd and 4th line repairs) are done at the 202 Workshop Depot in Montreal. This depot also has the responsibility to perform the 1st and 2nd line maintenance of all equipment returning from international missions. It is the only workshop in Canada performing 3rd and 4th line repairs to CF military equipment (www.forces.gc.ca/admmat/dglepm/202/eng/bienvenue-eng.asp).

4.2 Current and Planned Lift Assets

Canada currently has three types of airlift assets: CC-150 Polaris (Airbus 310-304), CC-130 Hercules (standard and stretched models), and CC-144 Challenger. The CC-150 provides excellent capability to transport personnel and cargo, however, it is capable of operating only on paved runways. It requires special handling equipment to load and off-load cargo and is not capable of air dropping equipment or supplies. The CC-150 Polaris has been modified to carry passengers and/or cargo in one of three configurations. The CC-130 Hercules provides capability to transport personnel and cargo. The runway surface on which CC-130's can operate must support the predicted maximum aircraft weight. The CC-130 is capable of air dropping equipment and supplies. The CC-144 Challenger is a business-jet aircraft and the Forces have six of them. Four CC-144 challengers provide VIP airlift support to the government and two provide utility transport for CF. It should be noticed that outsized cargo is defined as cargo that, because of length, width, height and/or weight, cannot fit into a Hercules-sized aircraft. Such cargo includes equipment such as the HLVW used by DART. The Forces are also acquiring four CC-177 Globemaster (Boeing C-17) strategic airlifters (for an estimated total cost of $1.8 billion). The CC-177 is a very robust asset for rapid strategic delivery of troops and all types of cargo. It is also capable of performing tactical airlift, medical evacuation and airdrop missions. The purchase of 17 tactical C-130J Hercules aircrafts (valued at approximately $1.4 billion) to replace some of the current fleet aging CC-130 Hercules.

Currently, the PROTECTEUR Class AORs (Auxiliary Oiler Replenisher) support naval operations by supplying fuel, lubricants, food, ammunition, spare parts, fresh water and stores, essential medical and dental services, and operating maritime helicopters. They also provide fleet support to joint operations ashore, and limited sealift in support of humanitarian/joint operations. However, the navy currently lacks the capability to provide significant support to forces ashore. Past operations requiring this capability had to use ad hoc arrangements. In addition, the cost of maintaining the current PROTECTEUR Class AORs is rising rapidly as their 35 year-old systems require increasingly more comprehensive overhauls and even replacement. For these reasons, the Canadian Forces are currently engaged in the acquisition of Joint Support Ships (JSS). The JSS will maintain the naval fleet support capability currently provided by the PROTECTEUR class, but they will also provide surge sealift, and support to forces ashore capabilities (DND, 2007). The JSS project, currently in the definition phase, will deliver the first of three ships in 2012.

The CF maintains large fleets of trucks (LSVW, MLVW and HLVW vehicles) to provide lift and logistical support on the ground. Much of this equipment is quite old, and the CF have announced recently the $1.2 billion acquisition of 2,300 new medium-sized logistics trucks (MSLT) to replace the MLVW. These MSLT will be used both for domestic and overseas operations. It will also provide the platform for integral unit logistics, provide mobile support facilities, effect resupply operations to deliver reinforcements and supplies, and provide for tactical movement to support operations across the spectrum of conflict (http://www.forces.gc.ca/admmat/dgmpd/msvs/index_e.asp).

The CF also maintains a fleet of utility transport tactical helicopter (the CH-146 Griffon) to support land force and humanitarian relief operations. However, recent CF deployments in Bosnia, Afghanistan, and Haiti, as well as relief operations such as those executed following the 2004 Tsunami, have demonstrated the requirement for integral medium-to-heavy lift helicopters (MHLH). Today the CF does not have a military helicopter to fulfil this role. The CF have consequently engaged in an estimated $4.7 billion project to acquire a fleet of 16 MHLH capable of safely and effectively moving CF troops and equipment in a threat environment, to support domestic and international operations (DND, 2006).

4.3 Third Party Resources and Collaboration with Allies

Figure 7 shows the increase of chartered airlifts expenses in the CF since financial year 97/98. Canada mainly charters Antonov AN-124s for strategic airlift and Boeing C-17s for strategic and tactical airlifts. The Canadian Forces are investigating a variety of options to improve the airlift capability while reducing operations costs. The variety of options investigated include contracted services, lease, lease to buy, purchase or potential ``teaming`` arrangements, such as the NATO Strategic Airlift Interim Solution (SALIS), in which fourteen countries join to share airlift resources. Through this solution, Canada is guaranteed 100 hours of AN-124 per year. The CF has also been using roll-on/roll-off (RO-RO) and load-on/load-off (LO-LO) cargo ships, for deployment and redeployment purposes. For example, during the deployment of Operation Athena, cargo was shipped from Montreal to Derince (Turkey) with two RO-RO and one LO-LO ships (Ghanmi, 2004), and the redeployment of Operation Apollo required one large RO-RO vessel (Ghanmi, 2005). Finally, at the tactical airlift level, the CF have relied on allied or coalition forces to provide medium-to heavy-lift helicopter transport while deployed.

Despite the fact that one of the limiting factors to a successful deployment into a theatre is the availability of very large aircrafts, very limited attention has been paid to alternate sealift options mainly due to tight temporal constraints or stringent requirements related to the creation of offshore storage facilities. Moving from expensive airlift to cheaper sealift might be perceived as an attractive sustainment option for deployed forces in case where requirements could be determined in advance over an appropriate timeframe with limited uncertainty. In other respect, the costs of chartered air and sealift in support of CF operations, combined to time and resource utilization constraints imposed by external factors or conditions dictated by specific operational environment, may seriously influence deployment times.

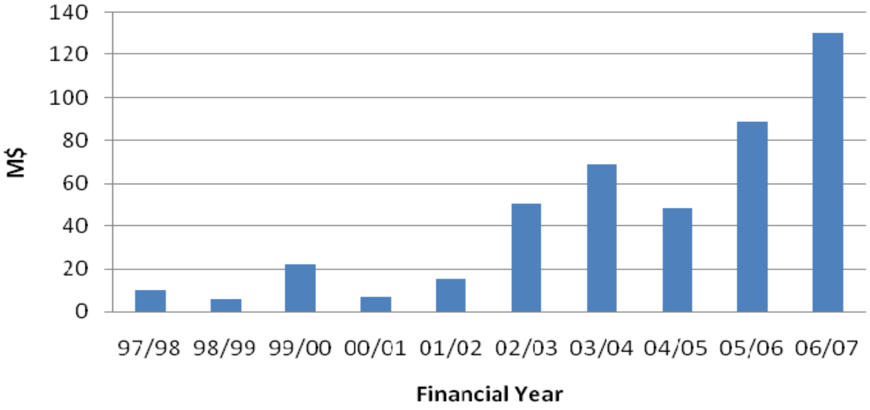

Figure 7. *Chartered Lift Expenses in the Canadian Forces*[8]

4.4 CF Overseas Mission Support Capability Gaps

The current transportation, warehousing, repair and intermodal transfer facilities of the Canadian Forces are insufficient to reach the international missions operational support goals stated in section 3.2. The numerous procurement projects cited previously (C-17, JSS, MSLT and MHLH) will improve strategic and tactical lift capabilities considerably, but they will not bridge the gap completely[9]. The main evidence to that effect is summarized below.

Deployment speed. As indicated in section 3.1, the current response time for humanitarian crisis missions ranges between 6 to 20 days, which is relatively long given that people rarely survive if not rescued within 3 days. For peacekeeping and peace enforcement missions, the current deployment period can last a few months. The acquisition of four Boeing C-17 strategic airlifters will contribute to improve the situation significantly, but since all missions are deployed from Canada, there is a threshold below witch we will not be able to go.

Sustainment efficiency. Currently, international missions are sustained directly from Canada, sometimes through an Intermediate Staging Base (ISB). Most transportation is done by air, which, as illustrated in Figure 7, has generated extremely high chartered-airlift expenses. The acquisition of the C-17 airlifters should help to decrease transportation costs, but transportation by air will remain expensive compared to sea or rail transportation. In addition, when there is a stock-out of a critical item at the operational theatre, it may be very difficult and expensive to fill it quickly, which has an impact on the quality of service provided. Furthermore, the consequence of the use of interim ISBs "has been a continual cycle of investment, education, use, and abandonment" (Boomer, 2004). This may represent an important loss of resources.

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[8] Source: LCol Thomas Gibbons, DND

[9] Strategic airlift capability gaps are discussed in detail by Mason and Dickson (2007).

Redeployment efficiency. The status-quo is expected to continue to prevail for redeployments. Given that more time is available when the mission ends, less expensive transportation modes can be used to bring materiel back to Canada, but this increases the period during which equipments and weapon systems cannot be used for other missions.

Robustness and resilience: With a supply depot at each extremity of Canada, and a single 3rd/4th line repair workshop in Montreal, the CFSN is very vulnerable to accidental, natural or wilful hazards threats. If one of these facilities is not able to operate during a significant downtime, it is unlikely that operational support will remain fast and efficient. Supply costs would increase significantly, and if part of the inventory held is destroyed, some essential items for the success of ongoing missions may be difficult to resupply.

As indicated in section 3.2, the design of a good supply network is a trade-off between service quality (responsiveness and fill rates), readiness investments and expenditures and operational support costs. It is believed that the current CFSN is not optimal, and that it could be improved by providing better service, at a lower cost, and by being more robust and resilient.

5 INTERNATIONAL PREPOSITIONING CAPABILITY OPTION

Several improvement directions can be examined to help bridge the overseas support capability gap previously identified, and thus to improve the global reach of the CF. Some of these directions are briefly examined in this section, but we concentrate on an option involving the implementation of a few prepositioning depots in adequate locations around the world. These overseas facilities would be used to stock insurance inventories, to provide 2nd and 3rd line maintenance, and to fulfil the role current played by ISBs for international missions, i.e. they would be flexible Operational Support Depots (OSD).

5.1 Possible Supply Network Improvement Options

Table 4 provides a description of the expected impacts of seven generic options to improve the support of overseas missions[10]. The first improvement direction involves the extension of the airlift capabilities of the CF. The recent acquisition by the CF of four Boeing C-17 strategic aircrafts, and the replacement of several C-130 (Hercules) tactical aircrafts, are moves in that direction. This option is limited however by the capacity of airports in potential missions' theatres. The measure of capacity commonly used for airports is the working MOG (maximum on the ground), that is, the number of aircraft that can be serviced and unloaded at one time. The working MOG for the airports of most developing countries is 3 or less (Peltz *et al.*, 2003) and, during missions, this is further limited by allocations to the various parties which must use the airport. This leads to the second improvement direction, which is to initiate actions to increase transportation infrastructures capabilities. This could be done by direct aid to developing countries or by investing in private infrastructures, but it is clearly a long-range option that relates more to government policy than military action.

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[10] The first five improvement directions are based on an analysis, performed by the RAND Corporation (Peltz *et al.*, 2003), of the options available for improving the deployment time of US Army units.

Improvement Direction	Direct Expected Impacts
1. Increase of lift assets capabilities	• Reduced deployment period within infrastructures limitations
2. Increase of transportation infrastructures capacity	• Reduced deployment period within assets limitations
3. Forward prepositioning of selected materiel	• Reduced deployment period by keeping selected material closer to potential missions • Reduced cyclic and safety inventory holding costs at missions sites because of shorter lead times when used as sustainment warehouse • Reduced transportation cost when used as an intermodal transfer point between sea and air lift
4. Improvement of mission planning process	• Reduced total preparation time by accelerating the deployment and load planning processes
5. Dynamic positioning of support ships	• Reduced deployment period by locating selected materiel closer to missions • Reduced sustainment transportation costs when used as an intermodal transfer
6. Standby suppliers for selected materiel	• Reduced deployment time • Reduced insurance inventory holding costs • Reduced sustainment transportation costs if suppliers are close enough to the mission • Reduced cyclic and safety inventory holding costs at missions sites because of shorter lead times
7. Collaborative networking with allies	• Reduced investment costs • Might also improve other performance metrics depending on the nature of the collaboration

Table 4. *Potential Improvement Directions for the Support of Overseas Missions*

The implementation of prepositioning depots in adequate locations around the world is the third generic option. We examine the details of this option in the next paragraph. The fourth improvement direction involves the acceleration of the mission planning process using generic mission types and resource modules ready to assemble according these mission types. The fifth option involves the dynamic positioning of support ships according to probable and on-going missions. These ships would stock selected equipments and supplies, and they would provide maintenance services. In order to be efficient, they would have to be medium-speed RO-RO ships and be equipped with transportation platforms for sea-based logistics such as the MV-22 tilt-rotor aircrafts, the CH-53E cargo helicopter, or the LCAC (landing craft-air cushioned) watercrafts used by the American Forces (Peltz *et al.*, 2003, Gue, 2003). The three Joint Support Ships (JSS) currently under procurement by the CF should be able to provide this type of support, even if they have a dual role, that is supporting navy fleets at sea and army forces ashore.

The sixth option can be interpreted as virtual prepositioning, since it involves the negotiation of supply contracts and standing offers with standby vendors and repair facilities, for materiel and/or services that can be externally procured. Vendors throughout the world could be selected to sign supply agreements that guarantee on-demand delivery to support missions' deployment and periodic deliveries for missions' sustainment. Note that this option is a complement to option 3, since it would be a natural role for Operational Support Hubs to negotiate and manage such contracts with vendors/contractors near their location (Boomer, 2006). The seventh improvement direction relies on a large spectrum of potential partnerships with other Forces that share the CF objectives. For example, A Multinational Intra-Theatre Distribution (MN ITD) concept for alliance or coalition operations is under examination by the Multinational LOGWAR Study Group (MLSG) – a UK force development process. MN ITD considers the creation of a multinational distribution centre that combines elements of the nations' stovepipes into a single system to improve distribution in a theatre of operation. The MN ITD performance was assessed by simulation, and compared against the current CF distribution system (Ghanmi *et al.*, 2008). The study indicates that a MN ITD system would potentially reduce the intra-theatre distribution response times by as much as 64% for common user items.

5.2 Increasing Global Reach with a Offshore Operational Support Network

Given that Canada is already well engaged in the development of lift assets (option 1) and Joint Support Ships (option 5), that option 2 is a long-range policy issue, and that option 4 pertains to continuous process improvement, the best structural avenue to further improve the capacity of the CF to deploy and employ forces off continent seems to be the implementation of a offshore network of Operational Support (or Prepositioning) Depots. The implementation of such a global supply network would build on improvement directions 3, 6 and 7. Boomer (2006) discusses the nature of OSDs in detail. Their main logistics roles and characteristics would be:

- Depot locations would be a regional hub for commercial distribution and movements, and have good communication infrastructures. They would also possess commercial and/or military equipment repair facilities that could be used to maintain CF materiel in theatre. The depots could also be shared with allied Forces.

- Depots would be in a relatively stable region and country favourably disposed to Canada and Canadian Forces members, relatively free of corruption, police and customs efficient and operating under a rule of law.

- Depots would hold an insurance inventory for selected materiel. Based on a Pareto (20-80 rule) analysis, these materiel would typically be items that are not too expensive, to avoid undue investment costs, but that require significant transportation resources. By deploying them to theatres from the OSD, instead of from Canada, the deployment speed could be accelerated significantly.

- Depots would hold cycle and safety stocks during the duration of the missions they support, and they would be able to act as an intermodal transfer point. This is crucial to be able to capitalize on the economy of strategic sealift options and of cargo consolidation, while maintaining the flexibility of resupplying the operations theatre on a frequent basis.

- Depots would incorporate a repair shop capable of providing selected 2nd and 3rd line maintenance activities. This would avoid backhaul costs to Canada for materiel that can be repaired at the OSD.

- Depots would develop and maintain a local network of external facilities that could be used to support CF activities, and have in place standing offers and contracts with key suppliers, repair facilities and hotels to permit rapid enactment for mission support. This local network could include friendly Forces facilities. It would be vital to deploy and sustain selected supplies that would be procured locally instead of being stocked.
- Depots permanent resources would be kept to a minimum to lower fixed costs, but they would expand as required to handle the throughput of personnel and materiel necessary to support the deployment, employment and redeployment phases of a mission.

It seems likely that an offshore network of Operational Support Depots would improve the CF's ability to deploy and sustain international missions, and that the savings obtained by avoiding unnecessary lift costs would outweigh added fixed and variable costs. A study conducted by Ghanmi and Shaw (2008), showed that 80% of the lift costs to support a mission occur during the sustainment phase. When most replenishments are done directly from Canada using strategic airlift, this is very expensive. With the implementation of an Operational Support Network, sealift could be used to replenish OSDs, which would reduce transportation costs considerably. Additional savings would come from the local procurement of some materiel to avoid shipments from Canada, and the local repair of equipments to avoid backhauling costs to Canada. This seems even more obvious when considering the current increasing fuel cost trend. Moreover, such a global supply network would be much more reliable and resilient than the current CFSN based on two Canadian supply depots. In addition to providing service for major missions, OSDs could support many small CF detachments operating overseas under UN mission headquarters or mandates.

In order to illustrate the feasibility of such a OSD network, based on Barnett's (2004) Pentagon's New Map, Figure 8 shows how major conflict-prone countries could be reached from a set of 6 prepositioning depots. Table 5 lists ten potential locations that would be natural candidates for the implementation of a CF OSD. These are only examples, however, and other locations in each region could also be considered.

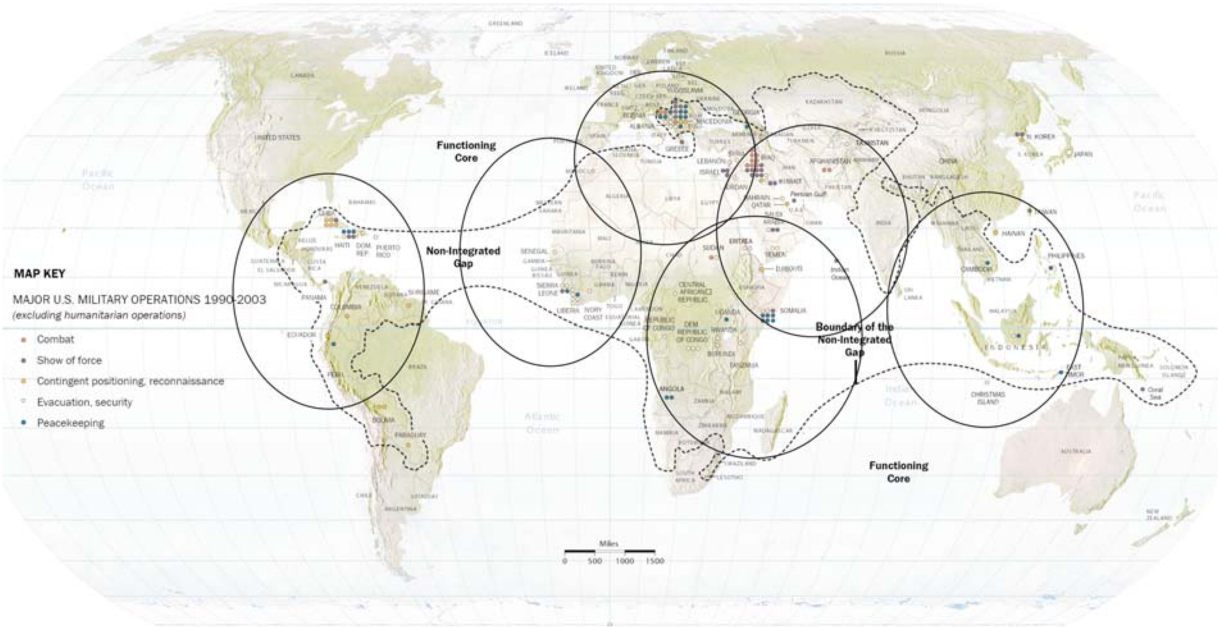

Figure 8. *The Pentagon's New Map, Barnett (2004)*

Region	Country	Location
Europe	Germany Italy	Ramstein, Bonn, Cologne Taranto
West Africa	Senegal	Dakar
East Africa	Kenya	Mombasa
South West Asia	UAE	Dubai
South East Asia	Singapore	Singapore
Central/South America	Panama	Panama
North-East Asia	Japan	Japan

Table 5. *Potential Overseas Operational Support Depot Locations*

5.3 Overseas Operational Support Network Design Decision Tradeoffs

Our previous discussion can be summarized in one important strategic question: *Is the implementation of an OSD network really cost-effective compared to the status-quo and, if so, what is the best network structure?* This question boils down to finding the structure of the optimal CF overseas supply network, the status-quo being a network without offshore OSD. The strategic decisions to make to do this were discussed in general terms in section 3.2. The design problem considered here is however somewhat simpler, for two reasons: 1) we assume that the domestic supply network, with its current embarkation/disembarkation points, will remain as it is and that only offshore OSD locations are considered as potential new supply network nodes; 2) given the important strategic and tactical lift expansion decisions made recently by Canada, we assume that no additional transportation equipment will be acquired by CF in the near future, and that any additional airlift or sealift capacity required will be provided by for-hire transportation. Also, given that the JSS are intended more as naval operations support ships and that they will not be available in the near future, we assume that they will not be used as dynamic prepositioning depots during the planning horizon of the problem considered.

Given these assumptions, the strategic decisions to make are the following:

1) the number of offshore OSDs to implement, their location and their capacity (in terms of warehousing and repair);
2) for all countries in the world (except Canada), the OSD location (including Canada) from which to support missions occurring in that country;
3) the amount (in the appropriate shipping unit) of insurance inventory to keep in each OSD, for all the product families defined in Table 4;
4) the operational support policy to implement for each mission type and geographical region.

As indicated before, the operational support policies specify maximum deployment period lengths and minimum frequency of carrier visits to theatres, and the supply network needed to guarantee these service levels involves readiness investments and expenditures, as well as operational support expenditures. These investments and expenditures being subject to limited budgets, adequate tradeoffs between costs and service must be sought. However, in practice, the budgetary mechanism involved being rather complex, it is not easy to formulate meaningful budgetary constraints. A simple surrogate for the readiness investment constraints could be to use an upper bound on the number of OSD one would accept to implement.

This network design problem is complex because it involves numerous conflicting objectives and because potential networks must be evaluated without knowing the missions the CF will have to support in the future. For example, when the number of OSD implemented is increased, the transportation costs are expected to go down, the deployment period to decrease, the frequency of theatre replenishments to increase and the robustness of the network to improve, all of which is positive. However, the facilities investment and operating costs, as well as the inventory holding costs are expected to increase, which is certainly not desirable. What are the best tradeoffs? It is not easy to answer this question, mainly under uncertainty. Providing an adequate answer requires the use of a relatively sophisticated risk assessment and decision methodology.

6 DESIGNING A ROBUST AND EFFICIENT OVERSEAS SUPPLY NETWORK

The approach proposed to answer the questions raised in the previous paragraphs is based on the generic methodology developed by Klibi and Martel (2008) for the design of effective and robust supply chain networks. The main elements of this methodology are summarized in the next paragraphs. We also indicate how it could be applied to design the CF overseas supply network.

6.1 Supply Network Design Methodology

Supply network design decisions are the responsibility of top management. At that level, the major preoccupations are the financing of the assets required, the expected return on these investments, and, more generally, the impact of the network design decisions on the capability of the organization to accomplish its mission. However, design decisions impose resource availability and utilization constraints on the *users* of the supply network which, through their daily supply, transportation and maintenance actions, in response to mission requirements, determine the return that will be obtained from the investment. Consequently, design decisions cannot be made without anticipating how the users will use the supply network.

The timing of the decisions made at the *design* and *user* levels must also be taken into account. At the beginning of the planning horizon, SCN design decisions are made and after an implementation period the network designed or reengineered becomes available for use during several usage periods. During these usage periods, users will support several military operations with the network designed. Furthermore, additional design decisions will be taken in time to adapt the network to its environment, which leads to replications of the design and usage planning cycle along the planning horizon considered. This gives rise to the multi-stage decision process illustrated in Figure 9 for two planning cycles. However, in a rolling horizon framework, the only decisions that will be implemented when the problem is solved at the beginning of the horizon are the first design decisions. Subsequent design decisions can be considered as future opportunities to adapt the network to its environment. During the planning horizon, several missions will have to be supported, and some disruptions may also affect the network. Unfortunately, at the beginning of the horizon, the future is not known. The best that can be done is to anticipate, with the information currently available, what the users and the designer will subsequently do to respond to the environment that will prevail and to adapt the structure of the network.

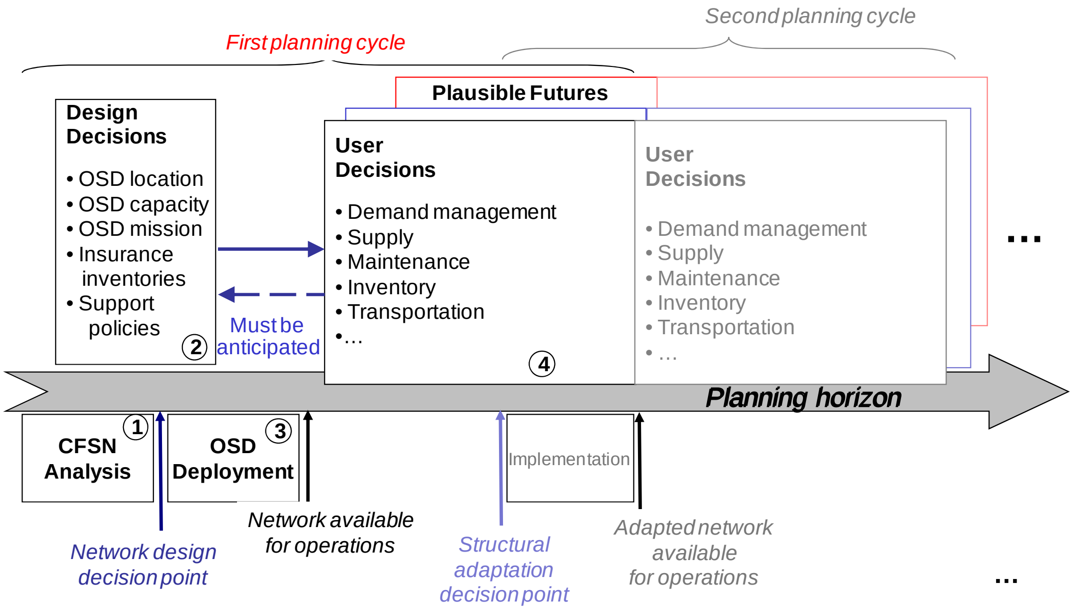

Figure 9. *Overview of the Supply Network Design Methodology*

Uncertainty reflects the inability to determine the true state of the future network environment, which may be partially known or mostly unknown. Depending on the nature of the information available, three types of uncertainties can be distinguished: aleatory, hazard and deep uncertainty. Aleatory uncertainty is characterized by random variables related to business as usual operations, hazard uncertainty by low probability unusual situations with a high impact, and deep uncertainty by the lack of any probabilistic information. The probabilities used to model aleatory and hazard uncertainty can be objective or subjective. The probability of an event is subjective if it represents a degree of belief of the occurrence of the event. In many contexts, mainly for hazard uncertainty, it is very hard to obtain sufficient data to assess objective probabilities and subjective probabilities must be used. The most practical way to model uncertainty is with a set of plausible scenarios about how the future may unfold. This naturally leads to the definition of aleatory, hazard and deeply uncertainty scenarios. The likelihood of aleatory and hazard scenarios can be assessed using objective or subjective probabilities. Deeply uncertain scenarios are typically narratives describing a plausible future, a worst-case situation for example, but it is not possible to assess their likelihood.

In our context, the main sources of uncertainty are related to future CF missions and to extreme events that could affect the supply network structure. This is best characterized by an adequate mix of hazard and worst-case scenarios. The events which may lead to CF missions or affect the supply chain can take several forms and it is important to find a practical way of taking them into account without getting lost into a maze of possible incident types. This can be done by considering hazards as a meta-event (multihazard) with generic impacts on network resources and demands. This leads to a multihazard modeling framework based on a number of key concepts: the identification of long-term evolutionary paths, the zonation of the territory into geographical zones (countries and regions in our case), the elaboration of zone *exposure indexes* by multihazard types (the failed state index for armed conflicts and the CRED natural multihazard index for humanitarian relief, for example), the definition of mission and incident profiles in terms of duration and intensity, and the characterization of multihazards likelihood through the use of incident arrival stochastic processes, attenuation probabilities and impact intensity probability distribution functions. With Monte Carlo simulation methods, these modeling constructs can be used to generate plausible future scenarios.

The concepts introduced in the previous paragraphs are the foundation of the methodology proposed in Figure 10 to obtain the most effective and robust supply network design. The methodology is essentially composed of three phases: scenario generation, design generation and design evaluation. The first phase is a Monte Carlo scenario generation procedure. Each scenario covers a complete planning horizon (say 10 years) and it details all the missions of different types performed in different countries during this period, as well as all the extreme events occurring at the OSD locations. It also specifies demand and repair profiles by product families for each weekly period during each mission. A scenario can be represented by a schema similar to the one presented in Figure 5 to summarize past CF missions. The scenarios produced are used in the design generation and the design evaluation phases, but the latter are defined over more aggregated time-periods (years instead of weeks).

The design model is typically a large-scale *stochastic program* solved for a relatively small sample of scenarios. This model finds the design providing the best cost-service tradeoffs for the scenarios considered. It includes a crude anticipation of the recourses necessary (for-hire transportation…) to cope with all the scenarios considered. In order to obtain different candidate designs, this model is run several times with different samples of scenarios. The design evaluation phase then compares the candidate designs with the status quo design. This comparison is based on the optimal planning and control decisions made by the network users for the design considered under a large sample of scenario. These lot-sizing, transportation and repair scheduling decisions are made using a relatively detailed user model. Since this model is solved for a single design and scenario at the time, it can evaluate costs and service levels much more precisely than the design model. Additional metrics can also be used to evaluate a design if desired, and the evaluation can be performed for worst-case scenarios. Comparisons are based on expected values, but also on selected dispersion measures to evaluate robustness. Based on all these multi-criteria evaluations, the candidate designs can be ranked, and a *best* design can be selected.

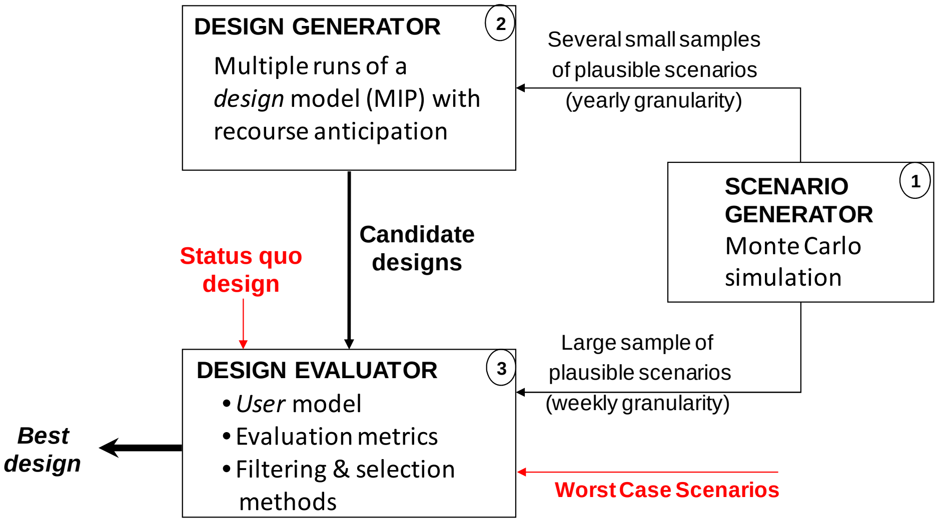

Figure 10. *Network Design Optimisation Approach*

6.2 Application to the Design of the CF Overseas Supply Network

In order to apply the methodology outlined in the previous paragraphs to the design of the CF overseas supply network, some modeling assumptions must be made, a Monte Carlo mission generation procedure must be developed and specific design and user models must be formulated and solved. In addition, the models and the solution algorithms used must be validated using a fictitious case that is as realistic as possible. During the proof of concept phase of the methodology development process, the validation case used should be based on as much non-sensitive real data as can be obtained without incurring undue data collection costs.

The general assumptions made about the operational support activities to be performed, and the movements in the overseas supply network to be designed, are summarized in the conceptual activity graph of Figure 11. Products are sourced either internally from Canadian CFSN points of embarkation, or from external vendors such as Original Equipment Manufacturers and local suppliers on OSD/theatre locations. Using available transportation assets or for-hire transportation, missions' theatre supply units are supplied either from an OSD, from Canada or from external vendors.

Prepositioning depots are supplied from the domestic CFSN or from external vendors. In some cases, the use of intermediate intermodal transfer points may be required. During and after a mission, some products may be recovered from the theatre supply as serviceable or unserviceable products. Some unserviceable products are shipped to an OSD, stored and eventually repaired before being stored or shipped as serviceable products. Some unserviceable products may also be shipped back to Canada directly or after an inspection at an OSD.

The design and user models formulated must be an adequate compromise between realism and ease of solution. The main assumptions required to reach an adequate compromise are discussed in the following paragraphs.

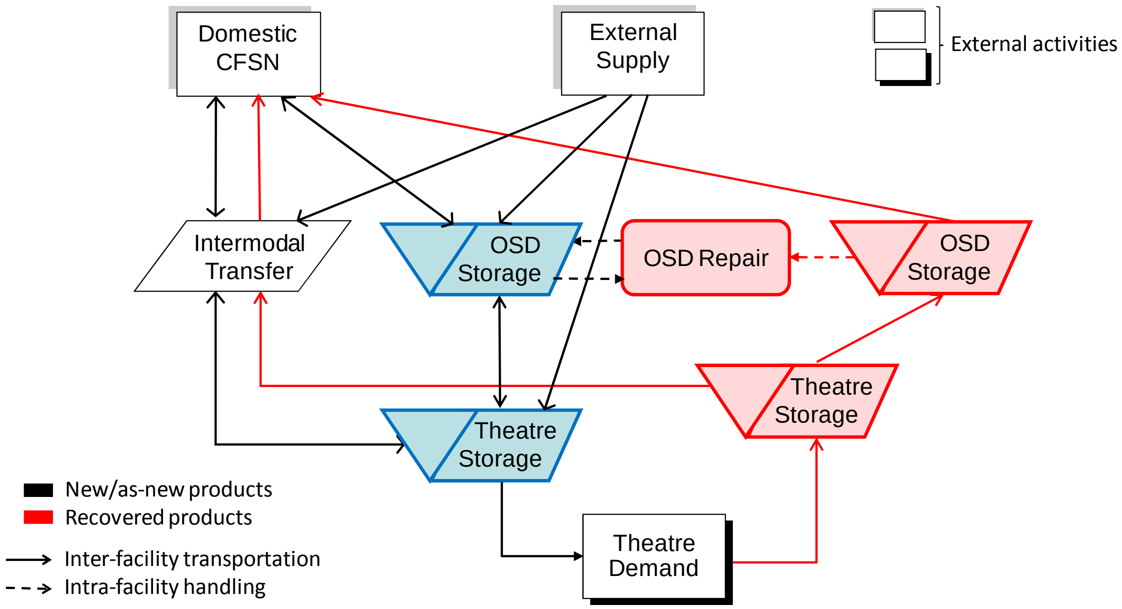

Figure 11. *CF Overseas Supply Network Activity Graph*

Time Horizons. The design and user models cover a single 10-year planning cycle. This means that the overseas network designed must support the needs of the CF over the next ten years. The planning horizon is divided into planning *periods*. Potential design evaluations are based on all the planning periods in the horizon. User level scenarios are defined over weekly periods, but they are aggregated into years at the design level to reduce the size of the design model.

Mission Modeling Process. In order to generate plausible 10-year overseas deployment scenarios, it is necessary to model the CF missions' *arrival process* and their supply *need profiles*. It can be assumed that the overseas events requiring humanitarian assistance, peacekeeping and peace enforcement interventions are independent, and that they occur randomly at a known rate in a given country. However, depending on Canada's foreign policy and on the troops already deployed at a given point in time, the arrival of a critical event does not necessarily lead to a CF mission. This can be modeled by an *attenuation probability*. Mission *duration* and *intensity*, can be expressed in term of the number of company deployed during a number of planning periods, and are subject to an upper bound on the total number of companies that can be deployed overseas by Canada at the time considered. Needs during a mission depend on the number of companies deployed, and on the mission stage (preparation, deployment, sustainment and redeployment). Needs also depend on the conditions under which operations are conducted.

Products and Capacities. The product *types*, *categories* and *families* defined in Table 4 can be used to reflect network needs, and transportation, repair and storage resource consumption. A product *states* can also be used to distinguish serviceable and unserviceable materiel. The capacity of the activities and movements represented in Figure 12 can be constrained by different types of resources. Product weight and volume are the main resource consumption dimensions considered in the CF context.

Transportation Assets. Movements can be carried out by one or several means of transportation. At the design model level, it is sufficient to consider aggregated means of transportation, namely: strategic airlift, tactical airlift and sealift. At the user model level, detailed asset types should be considered. Internal and external transportation assets must be distinguished.

Geopolitical Regions and Locations. Geopolitical *regions* are group of countries to which the CF assign the same service targets. Service targets are expressed in terms of deployment lead-time and sustainment supply frequency for theatre locations, and in terms of supply frequency for OSDs. A *location* is a geographical point or area where internal or external activities may occur. In the CF case, the locations to consider are potential vendors (domestic or overseas suppliers), prepositioning depots and operational theatres. Potential OSD locations are major cities with adequate commercial and transportation infrastructures. It can be assumed that there is no more than one depot location considered per country. Potential mission theatres are associated to countries, and for computational purposes, it can be assumed that the location of the theatre depot in that country is known (ex: Kandahar in Afghanistan).

Platforms. Potential repair and storage facilities in a given country can be represented through *platforms*. Each platform has specific capacities (maximum storage/repair throughput) and fixed costs (lease, cost of reaching an agreement with the host country…). Several platforms of different capacity and cost may be considered for a given OSD location.

Inventories. Insurance inventories and *cycle and safety stocks* must be distinguished. The former are kept permanently at the OSD in order to permit faster and cheaper deployments. The latter are observed during the sustainment phase of a mission because of transportation lot sizing and of the buffers needed to protect against mission uncertainties. The inventories kept are constrained by the depots storage capacity and by the transportation assets used. Cycle and safety stocks result from incoming flows at prepositioning and theatre depots and they depend on the specified service level.

Support Policies. OSDs and operational theatre depots can operate under different *support policies*. Policies specify desired service levels, mainly through supply profiles, i.e. by restricting potential supply sources and means of transportation to a predetermined set of locations and assets. It can be assumed that the depots and operational theatres in a given geopolitical region are bound by a same policy, independently of the mission type. More specifically, a policy for a prepositioning or theatre depot can be characterized by a supply frequency for each product category, which affects the level of cycle and safety stocks to be kept. For theatre depots, in addition to specifying the supply frequencies during the sustainment stage, a policy specifies a deployment lead-time common to all product categories. The deployment lead-time affects the course of missions and shapes demand and return profiles.

The aim of the design model formulated is to identify good candidate SN designs for further evaluation. Specifying a design involves the following decisions: the set of locations where an OSD should be implemented, the platform selected for each location, the level of insurance inventory kept for each product at each OSD, the potential theatres to be supported by each OSD, and the support policies to uphold for each geographical region. These decisions should be made to minimise negative deviations from support level goals, for a given set of plausible future scenarios, considering the following constraints:

- Budget restrictions
- Platform selection at OSD locations
- Service policy selection at OSDs and mission theatres
- Single sourcing
- Demand fulfilment
- Return fulfilment
- Flow equilibrium at OSDs
- Insurance inventory level at OSDs
- Cycle and safety stock level at depots
- Depot storage capacity
- Repair capacity at OSDs
- Transportation capacity
- Transportation infrastructure capacity at OSD and theatre locations

Each candidate supply network structure obtained with the design model, as well as the status quo solution (support from Canada), must be evaluated for a large sample of weekly-granularity scenarios with the help of a user model that represents supply operations as closely as possible (see Figure 10). More specifically, for a given network design and a given plausible future scenario, the user must decide, for each period of the planning horizon, how much internal and external transportation assets are to be assigned to each network lanes, and how many shipping unit of each product are to be shipped on these lanes. The aim of these decisions is to fulfill the needs of each operational theatre, during all mission phases, using internal transportation asset and OSD capabilities, while respecting support policies and minimizing backorder costs and for-hire transportation costs. Products recovery at theatre depots and repairs at OSDs must also be planned, and inventory levels at prepositioning and theatre depots must be tracked.

These detailed tactical decisions permit a relatively precise evaluation of operational costs and service levels. When, for a given design, the evaluations of all the scenarios considered are combined, expected costs and service levels, as well as confidence intervals, can be computed. These expected costs and service levels, combined with the readiness investment costs and expenditures associated to the design decisions, provide a global evaluation of a candidate design. Potential designs can then be compared from both effectiveness and robustness point of views to reach a final decision.

7 CONCLUSION AND RECOMMANDATION

Given Canada's commitment to continue contributing to the solution of emerging international conflicts and crisis, it seems clear that the global reach capabilities of the Canadian Forces must be enhanced. International missions are complex and diverse, and it is important for their success to improve the CF overseas mission deployment speed and sustainability. The current CFSN is largely domestic and international missions are supported from Canada. The CF made significant investments recently to upgrade its strategic and tactical airlift capabilities, an important step to improve its ability to deploy quickly from Canada. However, there is a limit to what can be done efficiently from Canada. This document has examined another option to improve the CF global reach: the possibility of developing an overseas network of Operational Support Depots. We have shown that this option has the potential of improving deployment speed, sustainment efficiency, as well as the CF supply network robustness and resilience.

Although the concept of an overseas supply network is relatively easy to value, the specific question of the number, location and mission of the depots to implement is much more difficult to answer. In the previous section, we have suggested using a generic supply network design methodology, developed by the DRESNET (Design of Robust and Effective Supply Network Engineering Tools) team at *Université Laval*, to address this question, and we have briefly indicated how this methodology could be applied to design an overseas OSD network. In order to demonstrate that this methodology can indeed be applied to the CF context, and is likely to provide a superior design, it should first be tested on a realistic but fictitious case built to be as close as possible to the real CF overseas network context. Once this proof of concept done, the best avenue would be to develop a generic computer aided design tool to facilitate the application of the methodology, and to use it to solve the real CF case. This tool could subsequently be employed by CANOSCOM to continuously improve its supply network as needs evolve and as the international and national context change.

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