Humanitarian Relief Operations: A Military Logistics Perspective

A Position Paper

S. Sebbah
NSERC Visiting Fellow, CJOC Operational Research & Analysis

A. Boukhtouta
CJOC Operational Research & Analysis

A. Ghanmi
CJOC Operational Research & Analysis

DRDC CORA TM 2012–260
November 2012

Defence R&D Canada
Centre for Operational Research and Analysis

CJOC OS Operational Research and Analysis

National Defence　Défense nationale

Canada

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Defence R&D Canada – CORA

Technical Memorandum

DRDC CORA TM 2012-260

November 2012

Principal Author

Original signed by S. Sebbah

S. Sebbah

Approved by

Original signed by I. Julien

I. Julien
Section Head, Land, Commands and Readiness

Approved for release by

Original signed by P. Comeau

P. Comeau
Chief Scientist, DRDC CORA

Abstract

Humanitarian logistics is defined as the process of planning, implementing and controlling the efficient, cost effective flow and storage of goods and materials as well as related information from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing. However, several factors may obstruct the flows of reliefs and information in humanitarian relief operations (HROs) and negatively affect the effectiveness of the involved organizations. Problems such as scarcity of reliefs and logistics means to efficiently distribute the goods, location/allocation of distribution centres and storage capacity, flow bottlenecks in the humanitarian relief network, security of convoys, fairness in reliefs distribution, etc. may appear at different stages of the HROs and prevent the reliefs from reaching the needy populations.

This study considers HROs from a military tactical logistics perspective. We review some challenging problems in HROs. We then propose mathematical planning and optimization models to address some of these problems. Finally, we give some concluding remarks and some future research venues.

Résumé

La logistique humanitaire, c'est la planification, la mise en œuvre et le contrôle du stockage ainsi que de l'acheminement, par des moyens efficaces et peu coûteux, de produits et de matériel, du point d'origine jusqu'au point de consommation, dans le but d'alléger la souffrance de personnes vulnérables. Cette fonction englobe toute une panoplie d'activités, dont la préparation, la planification, l'approvisionnement, le transport, l'entreposage, le suivi et le repérage. Cependant, plusieurs obstacles peuvent entraver l'acheminement des secours et perturber les communications (et l'information) dans le cadre d'opérations d'aide humanitaire (OAH) et ainsi nuire à l'efficacité des organismes participants. Certains problèmes, comme le manque de ressources et de moyens logistiques pour distribuer efficacement les produits, l'emplacement et la répartition des centres de distribution et leur capacité de stockage, les engorgements dans le réseau d'aide humanitaire, la sécurité des convois de même que l'équité de la distribution de l'aide, peuvent surgir à différentes étapes des OAH et empêcher l'aide de se rendre jusqu'aux populations qui en ont besoin.

Cette étude porte sur les OAH, du point de vue de la logistique tactique militaire. Nous passons en revue certains problèmes épineux auxquels les organismes participants à des OAH peuvent être confrontés. Nous proposons par la suite des modèles mathématiques de planification et d'optimisation pour résoudre certains de ces problèmes. Des conclusions et des pistes de recherches futures sont données à la fin du rapport.

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Executive summary

Humanitarian Relief Operations: A Military Logistics Perspective

S. Sebbah, A. Boukhtouta, A. Ghanmi; DRDC CORA TM 2012-260; Defence R&D Canada – CORA; November 2012.

Background: The 2011 triple disaster (earthquake, tsunami, and leaks of nuclear radiation) in Japan, the 2010 earthquake in Haiti, the devastating floods in Pakistan, the Sichuan earthquake, the 2005 Hurricane Katrina, and the 2004 Indian Ocean earthquake and tsunami, to name only a few, are among the most devastating natural disasters the last decade has seen. Disasters, when they strike, leave people without shelter, food, and in urgent need of medical assistance. In these situations, regional and international aids are necessary to supplement the local government and humanitarian organizations in absorbing the surge in demand for supplies.

The requirement for military support in Humanitarian Relief Operations (HROs) is situation dependent and is determined by a number of parameters including the type, scale, and location of the disaster, impact of the disaster on the stricken state coping mechanisms, and the assessed shortfall between disaster relief and victims' needs. The frequency of military intervention in HROs is expected to increase since it has been estimated that the number of disasters (natural, human made, and complex) will increase over the next 50 years. From the Canada's allies military perspective, a dominant paradigm driving perspectives on future humanitarian military missions is the *Comprehensive approach*, which argues that to meet the challenges of the future security environment, the involvment of, and cooperation with, allied defence teams, other government departments, the private sector and, where applicable, Non Governmental Organizations is required. In order for this approach to be effective, involved actors need to be adaptive to changing situations and should find the means of creating a more networked focus in order to benefit from the strength and capabilities of all active actors.

Humanitarian logistics is one of the most important aspects of disaster management systems. Civilian agencies ask for military help in HROs for several reasons, among which their logistics capabilities. Among the most wanted capabilities are transport (land, air, and sea), communications, medicines, tools and equipment, and security. Military humanitarian logistics is defined as the function, within the military logistics branch, dealing with the preparedness and responses phases of a disaster. The military emergency logistics encompasses the process of planning, implementing, and controlling the efficient flow and storage of goods and material as well as provisioning of infrastructure engineering support.

Objective and scope: In this report, we decided to address some of the tactical logistics problems in HROs, and set up some research directions for potential research efforts in the future. Therefore, this report should be seen as a position paper taking a large view at the military logistics problems in HROs. Although this research initiative is not formally requested by the Canadian Joint Operations Command, it is included in our research agenda as a component of a larger research project on developing military logistics planing and scheduling methodologies to improve Canadian Forces (CF) logistics effectiveness and responsiveness. This research work considers the HROs from the tactical logistics perspective.

Several factors may obstruct the flows of reliefs and information in HROs and negatively affect the effectiveness of the involved organizations. Problems such as scarcity of reliefs and logistics means to efficiently distribute the goods, location/allocation of distribution centres and storage capacity, flow bottlenecks in the HRO network, security of convoys, fairness in reliefs distribution, etc. may appear at different stages of the HROs and prevent the reliefs from reaching the needy populations. In this report, we discuss some of these challenging problems that involved organizations in HROs, particularly the military, may face, and proposes mathematical planning and optimization models. In particular, we explore the following research venues:

- Design of HRO network topology: We develop location/allocation models to define the optimal number and strategic locations of logistics nodes (depots and distribution centres), and to build potential routes. The capacity of the temporary storage locations will be explored and taken into consideration in the design of scheduling of relief distribution operations.

- Fleet mix and size of transportation assets: We develop optimization models to select the optimal set of transportation assets (air/land) for any afflicted area. We develop a strategy to select the optimal fleet mix and size of transportation assets to optimize the operating cost and maximize the effectiveness of the HROs.

- Bottleneck in the tactical logistics distribution network: We integrate in our design of HRO topology and the scheduling of relief operations some mechanisms to address the problem at both the strategic and operational levels. At the strategic level, the congestion is addressed by optimizing the storage capacity of the depots and distribution centres. While at the operational level, it is addressed by developing load balancing routing strategies to maximize the flow of supplies in the whole network.

In addition to these planning and scheduling topics, we discuss strategic issues like collaboration and cooperation of military with humanitarian logistics organizations and some advanced military logistics capabilities in HROs, e.g. radio-frequency identification and sense-and-respond logistics.

Significance of contributions and results: This report examined some military logistics dimension of HROs. It first described the context and roles of the military implications in HROs including typical environment characteristics, tasks and interactions with other organizations as well as logistics problems and planning factors involved in Humanitarian Relief (HR) logistics. Then, new mathematical models for scheduling HR distribution in a disaster relief operation over a multi-period horizon have been proposed. It focused on planning and scheduling distribution of multiple classes of supplies to demand points in a disaster area using two modes of transportation including air and land.

The proposed models jointly decide on the locations of the depots and the scheduling of operations. However, they could be used to perform optimization and analysis of several strategic and operational parameters separately as well as jointly. The solutions of the proposed models provide a scheduling plan and an optimal fleet mix and size given the different strategic parameters. From a strategic planning point of view, if the fleet mix and size were known then, the proposed models could also be used to detremine the locations of the depots, their storage capacities, and the optimal scheduling plan to distribute the supplies.

Sommaire

Humanitarian Relief Operations: A Military Logistics Perspective

S. Sebbah, A. Boukhtouta, A. Ghanmi ; DRDC CORA TM 2012-260 ; R & D pour la défense Canada – CARO ; novembre 2012.

Sommaire administratif : La triple catastrophe (tremblement de terre, tsunami et fuites radioactives) qui a frappé le Japon en 2011, le tremblement de terre à Haïti en 2010, l'ouragan Katrina en 2005 et le tremblement de terre suivi d'un tsunami dans l'océan Indien en 2004 sont parmi les catastrophes naturelles les plus dévastatrices survenues au cours de la dernière décennie. Lorsqu'un sinistre frappe, les gens se retrouvent sans toit ni nourriture et ont besoin d'une aide médicale d'urgence. En pareilles circonstances, l'aide internationale et l'aide régionale sont nécessaires pour aider le gouvernement local et les organismes humanitaires à absorber l'afflux des demandes de matériel.

Le besoin d'un soutien militaire dans les OAH dépend de la situation et est déterminé par un certain nombre de paramètres, dont le type, l'étendue et l'endroit du sinistre, ses conséquences sur les capacités de l'état frappé à réagir ainsi que l'écart évalué entre les secours aux sinistrés et leurs besoins. La fréquence des interventions de l'armée dans les OAH devrait s'accroître puisqu'on estime que le nombre de sinistres (catastrophes naturelles ou causées par l'homme et catastrophes complexes) augmentera au cours des 50 prochaines années. Dans les milieux militaires des alliés du Canada, une façon d'envisager l'avenir des missions humanitaires de l'armée domine et c'est l'approche globale, selon laquelle le contexte futur sur le plan de la sécurité nécessitera la participation d'équipes de défense alliées, d'autres ministères, du secteur privé et, au besoin, d'organismes non gouvernementaux et une collaboration avec ces intervenants. Pour que cette approche fonctionne, les intervenants doivent s'adapter aux situations changeantes et trouver les moyens de créer une approche en réseau qui permettra de mettre à profit les forces et les capacités de tous les intervenants.

La logistique humanitaire est l'un des aspects les plus importants des systèmes de gestion des catastrophes. Les organismes civils demandent de l'aide pour mener les OAH, et ce, pour plusieurs raisons, parmi lesquelles, les capacités logistiques requises. Parmi les capacités les plus demandées, il y a le transport (routier, aérien et maritime), les communications, les médicaments, les outils et le matériel de même que la sécurité. La logistique humanitaire militaire se définit comme la fonction de la logistique militaire qui s'occupe des phases de la préparation et de l'intervention en cas de catastrophe. La logistique des opérations d'urgence militaires comprend la planification, la mise en œuvre et le contrôle de l'acheminement et du stockage efficaces des produits et du matériel ainsi que la prestation d'un soutien à l'ingénierie d'infrastructure.

Objectif et étendue du rapport : Nous traitons dans ce rapport, certains problèmes de la logistique tactique propres aux OAH et nous proposons quelques pistes de recherches pour d'éventuelles études. Par conséquent, ce rapport doit être vu comme un exposé de principes couvrant l'ensemble des problèmes de la logistique militaire dans les OAH. Bien que cette étude n'ait pas été commandée officiellement par le Commandement des opérations interarmées du Canada, elle fait partie des études que nous menons dans le cadre d'un projet de recherches plus vaste sur la conception de méthodes de planification et d'ordonnancement s'inspirant de la logistique militaire dans le but d'améliorer l'efficacité et la rapidité des éléments logistiques des Foces Canadiennes. Ce travail de recherche prend en considération les OAH du point de vue de la logistique tactique.

Plusieurs obstacles peuvent entraver l'acheminement des secours et perturber les communications (l'information) dans le cadre d'OAH et ainsi nuire à l'efficacité des organismes participants. Certains problèmes, comme le manque de ressources et de moyens logistiques pour distribuer efficacement les produits, l'emplacement et la répartition des centres de distribution et leur capacité de stockage, les engorgements dans le réseau d'aide humanitaire, la sécurité des convois de même que l'équité de la distribution de l'aide, peuvent surgir à différentes étapes des OAH et empécher l'aide de se rendre jusqu'aux populations qui en ont besoin. Dans ce rapport, nous traitons de certains des problèmes épineux auxquels les organismes participant à des OAH, mais surtout l'armée, peuvent être confronés et nous proposons des modèles mathématiques de planification et d'optimisation. Plus particulièrement, nous explorons les pistes de recherches suivantes :

• La conception de la topologie du réseau pour les OAH : Nous présentons des modèles de localisation et de répartition qui permettent de définir le nombre optimal de points logistiques (entrepôts et centres de distribution) et leur emplacement stratégique et de tracer des parcours possibles. La capacité des lieux de stockage temporaires sera examinée et prise en considération dans l'ordonnancement des opérations de distribution de l'aide.

• La composition et la taille du parc de véhicules : Nous proposons des modèles d'optimisation permettant de sélectionner l'ensemble optimal de véhicules (aériens et terrestres) pour n'importe quelle région sinistrée. Nous présentons une stratégie pour sélectionner la composition et la taille optimales du parc de véhicules afin d'optimiser le coût de fonctionnement et de maximiser l'efficacité des OAH.

• La congestion dans le réseau de distribution logistique tactique : Nous intégrons dans notre conception de la topologie du réseau et l'ordonnancement des OAH quelques mécanismes pour remédier à ce problème au niveau stratégique et au niveau opérationnel. Au niveau stratégique, on remédie à la congestion en optimisant la capacité de stockage des entrepôts et des centres de distribution tandis qu'au niveau opérationnel, on conçoit des stratégies d'acheminement permettant d'équilibrer la charge de manière à maximiser l'acheminement du matériel dans tout le réseau.

Outre la planification et l'ordonnancement, nous traitons de questions stratégiques comme la collaboration et la coopération des militaires avec les organismes de logistique humanitaire et certains outils logistiques militaires de pointe utilisés dans les OAH, c'est-à-dire, l'identification par radiofréquence et la détection-réaction.

Importance des contributions et résultats : Ce document traite de certaines dimensions de la logistique militaire des OAH. Il décrit d'abord le contexte et les fonctions assumées par l'armée dans les OAH auxquelles elle participe, y compris les caractéristiques contextuelles, les tâches et les interactions typiques avec d'autres organismes ainsi que les problèmes de logistique et les facteurs influant sur la planification de l'aide humanitaire. Ensuite, de nouveaux modèles mathématiques d'ordonnancement de la répartition, sur plusieurs périodes, de l'aide dans le cadre d'une OAH ont été proposés. Il est alors surtout question de la planification et de l'ordonnancement de la distribution, par voies aérienne et terrestre, de diverses catégories de produits aux différents endroits où il y a une demande dans une région sinistrée.

Les modèles proposés dans ce document permettent la détermination de l'emplacement des entrepôts et la planification des opérations. Toutefois, ils peuvent être utilisés pour optimiser et analyser plusieurs paramètres stratégiques et opérationnels. Les solutions des modèles proposés permettent de définir le plan d'ordonnancement ainsi que la composition et la taille optimales du parc en tenant compte des différents paramètres stratégiques. D'un point de vue de planification stratégique, si la composition et la taille du parc sont connues, les modèles proposés pourront aussi être utilisés pour déterminer les positions optimales des entrepôts, leurs capacités de stockage et le plan optimal d'ordonnancement pour la distribution des produits.

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1 Introduction

The 2011 triple disaster (earthquake, tsunami, and leaks of nuclear radiation) in Japan, the 2010 earthquake in Haiti, the devastating floods in Pakistan, the Sichuan earthquake, the 2005 Hurricane Katrina, and the 2004 Indian Ocean earthquake and tsunami, to name only a few, are among the most devastating natural disasters the last decade has seen. Disasters, when they strike, leave people without shelter, food, and in urgent need of medical assistance. In these situations, regional and international aids are necessary to supplement the local government and humanitarian organizations in absorbing the surge in demand for supplies. A disaster is defined by the Centre for Research on Epidemiological Disasters as a "situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering" [1]. Disasters are on the rise[1] and they are more complex [2]. Disasters are termed *natural* if caused by an uncontrollable natural force and *man-made* if caused by human interference or the consequences of technological failures such as toxic material and gas releases. The frontier between the two types of disasters is not very clear. For example, the 2011 Japan's earthquake triggered a massive tsunami and several explosions at the Fukishima nuclear power plant. Added to this tremendous disaster, Japan has endured in 2011 one of its coldest winter. Indeed, winter storms complicated rescue and recovery after the Tsunami and the earthquake. Beyond these types of disasters, complex emergency resulting from conflict induced conditions and very often coming with natural disasters, have intensified over the last decades in many regions of the world [1]. A complex emergency is defined by the Inter-Agency Standing Committee Working Group as "a humanitarian crisis in a country, region or society where there is total or considerable breakdown of authority resulting from internal or external conflict and which requires an international response that goes beyond the mandate of any single United Nations (UN) country program" [3]. In complex emergencies, affected populations are very often cut off from their sources of income and lose their security, owing to displacement of populations. Wars and civil disturbances that destroy homelands and displace people are considered by certain organizations among the causes of complex disasters [1]. In addition to the direct impact on the affected populations, there is increasing awareness that both natural and complex disasters have significant environmental consequences and long-term implications of those affected populations.

Use of Military Forces (MF) in support of humanitarian operations is a long-established practice. In the public belief, there is often a high expectation that the military will be involved in the immediate aftermath of conflicts and large-scale disasters. The requirement for military support in Humanitarian Relief Operations (HROs) is situation dependent and is determined by a number of parameters including the type, scale, and location of the disaster, impact of the disaster on the stricken state coping mechanisms, and the assessed

[1] The increase in the number of disasters is explained partly by better reporting of disasters in general and partly due to real increases in both the frequency and the impact of certain types of disasters.

shortfall between disaster relief and victims' needs. The frequency of military intervention in HROs is expected to increase since it has been estimated that the number of disasters (natural, human made, and complex) will increase over the next 50 years [4]. From the Canada's allies military perspective, a dominant paradigm driving perspectives on future humanitarian military missions is the *Comprehensive approach* [5,6], which argues that to meet the challenges of the future security environment, the involvment of, and cooperation with, allied defence teams, other government departments, the private sector and, where applicable, Non Governmental Organizations (NGOs)is required. In order for this approach to be effective, involved actors need to be adaptive to changing situations and should find the means of creating a more networked focus in order to benefit from the strength and capabilities of all active actors.

Military involvement in HROs should be driven by need and be respectful of the principals of humanity, neutrality and impartiality. In HROs, any military-civil coordination must first serve the prime humanitarian principals of humanity. Determining the extent to which humanitarian agencies should coordinate with MF to minimize the consequences of close affiliation, or even perception, as these could jeopardize the humanitarian principals of neutrality and impartiality, is not obvious. In some disaster situations there may be some tensions that may be exacerbated by the presence of MF. To establish a climate of confidence among the different actors and the stricken state government it is necessary that the intent of the MF is clearly understood by all involved actors. Transparency of intent is crucial to a successful coordination among the involved actors, and required to reduce the mistrust that may result from the military presence.

Humanitarian logistics is one of the most important aspects of disaster management systems. Civilian agencies ask for military help in HROs for several reasons, among which their logistics capabilities. Among the most wanted capabilities are transport (land, air, and sea), communications, medicines, tools and equipments, and security. Military humanitarian logistics is defined as the functions, within the military logistics branch, dealing with the preparation and responses phases of a disaster. The military emergency logistics encompasses the process of planning, implementing, and controlling the efficient flow and storage of goods and material as well as provisioning of infrastructure engineering support.

1.1 Humanitarian relief operations and the Canadian Forces

Inside Canada, the Public Safety Canada (PSC) is the main department responsible for coordinating the response to natural disasters. Abroad, the Department of Foreign Affairs and International Trade (DFAIT) coordinates the Government of Canada response to major natural disasters and HROs [7]. Over the last decades, Canada has been internationally involved in several HROs to help relief populations in need. The most recent are: the earthquake in Japan (March 2011), earthquake in New Zealand (February 2011), the floods in Pakistan (July/August 2010), the earthquake in Chile (February 2010), and the earthquake in Haiti (January 2010) [7]. The 2010 earthquake in Haiti, was probably the natural disaster where Canada has taken major actions and extensively used the Canadian Forces (CF) to support its HROs. Within hours of the earthquake, military and civilian experts from different departments, including search and rescue technicians, medical and logistics personnel, engineers, and humanitarian and disaster victim identification experts had been deployed to Haiti. The CF have played a major role in Canada's efforts to stabilize the situation in Haiti.

Different components of the CF are used, when required and possible, to support the Government of Canada's efforts in some disaster areas. The Disaster Assistance Response Team (DART) is the first team within the CF that is deployed to provide basic medical assistance and clean water. The DART is used as a stabilization tool to provide essential services to meet medium term needs until the affected government and/or humanitarian agencies can get them back to normal. Given its capabilities and mission, the DART is not designed to provide first response services (e.g., search and rescue). However, it can be used as a stabilization tool in the government of Canadian's response in situations where the capabilities of local governments and humanitarian agencies to provide essential services (primary health care and potable water) are overstretched. Other military components, for example, medical staff, search and rescue teams, logistician might be deployed, if necessary and required, to support and complement the DART efforts. The CF relief operation for Haiti (the operation was called HESTIA by the CF) is an example of a large deployment of different CF corps (maritime, land, and air) in HROs. The Joint Task Force Haiti (JTFH) is the task force within the CF involved in Operation HESTIA. Its mandate was to deliver a wide range of services including emergency medical services, engineering expertise, mobility by sea/air, and defence and security support to the Haitian government and the Canadian Embassy in Port-au-Prince. During the HESTIA mission, the JTFH has treated 22,290 patients, moved around 5,722,396 pounds of supplies, distributed 1,404,940 individual meals (provided by aid agencies), and produced 2,585,077 litres of water, etc [8].

1.2 Objectives

In this report, we decided to address some of the tactical logistics problems in HROs, and set up some research directions for potential research efforts in the future. Therefore, this report should be seen as a position paper taking a large view at the military logistics problems in HROs. Although this research initiative is not formally requested by the Canadian Joint Operations Command (CJOC), it is included in our research agenda as a component of a larger research project on developing military logistics planing and scheduling methodologies to improve CF logistics effectiveness and responsiveness. This study considers the HROs from the tactical logistics perspective. It is a follow up on a previous study on military tactical logistics [9] with a main focus on HROs.

Several factors may obstruct the flows of reliefs and information in HROs and negatively affect the effectiveness of the involved organizations. Problems such as scarcity of reliefs and logistics means to efficiently distribute the goods, location/allocation of distribution centres and storage capacity, flow bottlenecks in the HROs network, security of convoys, fairness in reliefs distribution, etc. may appear at different stages of the HROs and prevent the reliefs from reaching the needy populations. In this report, we discuss some of these challenging problems that involved organizations in HROs, particularly the military, may face, and propose mathematical planning and optimization models. In particular, we explore the following research venues:

- Design of HROs network topology: We develop location/allocation models to define the optimal number and strategic locations of logistics nodes (depots and distribution centres), and to build potential routes. The capacity of the temporary storage locations will be explored and taken into consideration in the design of scheduling of relief distribution operations.
- Fleet mix and size of transportation assets: We contribute optimization models to select the optimal set of transportation assets (air/land) for any afflicted area. We develop a strategy to select the optimal fleet mix and size of transportation assets to optimize the operating cost and maximize the effectiveness of the HROs.
- Bottleneck in the tactical logistics distribution network: We integrate in our design of HROs topology and the scheduling of relief operations some mechanisms to address the problem at both the strategic and operational levels. At the strategic level, the congestion is addressed by optimizing the storage capacity of the depots and distribution centres. While at the operational level, it is addressed by developing load balancing routing strategies to maximize the flow of supplies in the whole network.

In addition to these planning and scheduling topics, we discuss strategic issues like collaboration and cooperation of military with humanitarian logistics organizations and some advanced military logistics capabilities in HROs, e.g., radio-frequency identification (RFID) and sense-and-respond logistics.

1.3 Report organization

The remainder of this report is organized as follows. Section 2 describes the military HROs. Section 3 details the military role in the HROs from a logistics perspective. Section 4 presents mathematical models and a solution approach based on Column Generation (CG) for scheduling HROs in a disaster relief operation. Several aspects of the HROs are included in the optimization model and discussed with their effects on the global HROs efficiency and effectiveness. Two illustrative HROs scenarios are presented in Section 5 with some computational results. Finally, some concluding remarks and future research trends in the field of military HROs are given in Section 6.

2 Military and the Humanitarian Relief Environment

In this section, we discuss some characteristics of the emerging environment where the MF will continue to intervene and their impacts on the HROs. We also discuss the military role in the disaster response cycle and their carried activities in HROs. The interaction between military and civilian Humanitarian Relief (HR) organizations is also discussed at the end of this section.

2.1 Emerging environment characteristics

The characteristics or the trends of the emerging humanitarian environment, in which the MF and HR actors are operating, can be described as follows.

2.1.1 Volatility and uncertainty

Involved actors in HROs are facing several challenges in building their relief plans due to the uncertainty and volatility characterizing most of the HROs activities. Uncertainties about the location and intensity of the disaster, volatility of demands, aid volatility and uncertainty, imbalance between supply and demand, and disruptions in the distribution system are all factors that affect military and civilian HR supply chains. These factors have often complicated relief policy implementation, especially in countries where a large part of government spending is financed by international aid. Along with natural disasters, food scarcity and price volatility will continue to affect food and other basic goods for the next decades in HROs.

2.1.2 Globalization

It refers to the increased mobility of goods, services, technologies, etc. around the world. Globalization goal is to increase material wealth, goods, and services through an international division of labour by efficiencies catalyzed by international relations and signed agreements. As consequences of globalization, societies have become integrated through communication, transportation, and trade. Globalization could increase interdependence of MF of different countries and encourage them to adopt shared processes and resources for emergency relief operations. Globalization also would facilitate the transfer between the military institutions and allies of the technological innovations useful for HROs.

2.1.3 Multinational and public humanitarian environment

States will continue (via their MF, etc.) to represent the key actors in HROs. However, non-state actors will continue to function as significant players in the theatre of operations. These non-state actors are represented by international organizations such as the UN and its agencies as well as NGOs, multinational corporations, and humanitarian organizations engaged in the provision of humanitarian aid and assistance to victims. The need for more coordinated and holistic approach to operations is ever more evident. From Canadian perspectives, the Department of National Defence (DND) has called for a force that is joint, interagency, multinational and public (JIMP)-enabled. Such a force would see the resources and processes (dedicated for HROs) aligned with those of other agencies and coordinated through a global plan and applied in the areas of operations. As such, the approach would see the military activities being carried out collaboratively within a context of a comprehensive approach involving the coordinated actions of the military with the other instruments of national power.

2.1.4 Scientific and technological innovation

Strategic science and technology programs put forward last decade by different governments in the public safety and emergency management fields are contributing significantly to technological innovation and rapid scientific growth [10, 11]. The aim of these programs is to gather scientific expertises in order to solve the major scientific problems encountered during emergency relief operations and to develop forecasting models for effective and efficient relief operations management. Typical problems include automated identification (e.g., emergency supply such as food/water, clothes, shelter or ambulance and health experts' location), transportation routing and scheduling (e.g., efficient patient evacuation or food delivery to demand sites), demand forecasting (basic commodities such as water, food, blankets and tents), monitoring (disaster evolution and demand satisfaction and impact on recovery, anticipated undesirable situation), automated assistance to demand response (e.g., the use of robots to deliver supply, sustain demand and rescue). Different Organizations (e.g., DND) are involved in these research programs. Recent technology developments to assist emergency logistics supply chain management enhancing supply chain visibility and optimality, and reducing logistics costs and footprint are numerous. Automated identification, RFID mesh, and most general sensor network technology look particularly promising and helpful in providing total asset and resource visibility and ultimately end-to-end supply chain visibility, while facilitating near real-time asset readiness assessment and management. Emerging problem-solving procedures based on meta-heuristics and agents, and the synergy of available analysis methods (through supply network simulation; asset, situation and plan execution monitoring; model checking for situation assessment, data mining and demand/plan execution forecasting) are increasingly applicable to the HRO context to take on integrated logistics decision challenges leading to supply network optimality. In contrast, green logistics and sustainable development practices represent promising approaches in significantly reducing logistics costs and footprint. Robotic systems (e.g., unmanned autonomous systems) able to achieve multiple roles concurrently (e.g., tactical airlift cargo transportation, logistics route reconnaissance, medical evacuation, and search and rescue) constitute an alternate technology to reduce the logistics footprint.

2.1.5 Complex in-theatre relief operations

Humanitarian and military actors have fundamentally different thinking and cultures, mandates, objectives, and working methods. Coordinating different actors in order to increase the relief efficiency and effectiveness is among the most challenging in-theatre operations. Within the context of civil-military relations, there is a number of operations where humanitarian actors and military may coordinate their efforts. However, collaborations where each actor pursue a specific objective, are encouraged and necessary to minimize competition and conflicts. From a logistics perspective, the lack of coordination and cooperation among the humanitarian actors may cause some problems in the relief distribution chain. These problems include congestion in the relief distribution network [4], storage capacity of distribution centres and depots [12], and safety of supply, vehicles, humanitarian organizations and their personnel. The congestion problem may happen at different locations in the supply topology, e.g., depots, Local Distribution Centres (LDCs), and routes. This problem is mainly due to the difficulty to coordinate the HR efforts in disaster areas. Congestion may limit the availability of supplies, and causes ineffective distribution of aids [13]. The problem of planning the storage capacity of the support network nodes is closely related to the congestion problem at those nodes. This problem, not well studied in the context of HROs, needs more attention to ensure fair and effective distribution of supplies through pre-positioning of supplies during the disaster relief operation.

2.1.6 Threat

Some humanitarian environments are characterized by threats to affected populations and humanitarian relief agencies. They are usually due to conflicts where civilian are located in areas difficult to access. The threat environment is characterized as being (1) permissive: the host nation has power to maintain order in the afflicted area, and the government has the capability to assist in the HROs. Therefore, humanitarian actors may provide assistance with less worries about their safety; (2) uncertain: the host nation does not have full control of the afflicted territories and populations. The possibility of obstruction from individuals, crowds or mobs, or organized factions are not inexistent; (3) hostile: hostile forces have control over the afflicted areas and have capabilities to obstruct and deny any assistance to an at risk populations. The nature of the environment may also decide on the involvement of military in HROs. In hostile environments where humanitarian organizations are denied access to afflicted populations and supplies might be used by belligerents for their own purpose, the military involvement might be the only alternative for humanitarian organizations and the host nation.

2.2 Military involvement and role in humanitarian relief operations

Most often military involvement is requested in response to a sudden and unexpected disaster. The threat environment and the magnitude of a disaster may also call for military involvement. The current Canadian foreign policy is to ensure an effective, appropriate, coordinated and timely response to humanitarian assistance, peacekeeping (stabilization) and peacemaking (peace enforcement) needs around the world. Through its engagements with the UN and the North Atlantic Treaty Organization (NATO), Canada, through its governmental agencies and military forces, is likely to be involved in these three types of missions. When not directly involved in providing security to humanitarian organizations, the CF may be required to assist in planning or providing advice on security for governmental and non governmental humanitarian organizations.

In some situations, it is important to maintain a clear separation between the military and humanitarian organizations by separating their respective duties and responsibilities. This is especially important in some particular conflict areas. Any coordination with a party involved in a conflict must be carefully studied given that a perceived affiliation with a belligerent might lead to the loss of neutrality and impartiality of the humanitarian organization. This in turn may affect the security of beneficiaries and humanitarian staff. However, at the same time humanitarian actors need to find efficient and effective ways to ensure delivery of vital assistance to afflicted populations. Therefore, a balance has to be found for each situation between the perceived affiliation with the military and the safety/effectiveness of relief operations. To stick to their principles of humanity, neutrality, and impartiality, most humanitarian organizations perceive the decision to seek military-based assistance as the last resort option when other mechanisms are unavailable or inappropriate.

It is well accepted that where and when humanitarian capacities are not adequate and cannot be obtained in a timely manner, military capabilities may be deployed in accordance with the *Guideline On The Use Of Military and Civil Defence Assets to Support United Nations Humanitarian Activities in Complex Emergencies* [14]. The key criteria in the guidelines include (1) unique capability, i.e., no appropriate alternative civilian resources exist, (2) timeliness, i.e., the urgency of the operation requires immediate action; (3) clear humanitarian direction, i.e., military assets remain under the military control, but the control over the use of military assets is under the civilian (humanitarian organization) control; (4) time-limited, i.e., the use of military assets to support humanitarian activities should be limited in time and scale.

MF when deployed in disaster areas may carry out humanitarian tasks themselves or support the efforts of other agencies involved in the HR efforts. The tasks may therefore cover a large spectrum of activities ranging from the distribution of provision to simply providing security to tierce organizations. The military support can be classified, based on the degree of implication of the military in the relief efforts, as follows:

- Direct support: this is the peer-to-peer distribution of supplies and services. This activity is common in HROs, where MF are highly involved, and implies direct delivery of good to affected people.
- Indirect support: support is provided to agencies directly involved in distribution of goods to population. This way of support involves such activities as transporting relief goods, security, and protection to humanitarian activities. This is very common in hostile areas where military support is required to protect convoys and ensure safety of personnel.
- Infrastructure support: this involves providing services in the direct and indirect ways. Activities such as road and bridge repair, airspace management, water, and power generation are provided both to affected population and to help relief organizations.

Table 1 presents some of the traditional and non-traditional military operations which are conducted in a direct, indirect, and as infrastructure support ways.

In addition to their traditional tasks (i.e., civil engineering, logistics, and security) MF involved in HROs have been allocated tasks that are non-traditional military tasks. Among these tasks:

- Providing protection for humanitarian assistance: because of the uncertainty and hostility of the crisis area, humanitarian aid might not reach the needy people. In this case, military protection may be needed to ensure an effective delivery of goods to the various elements in the whole relief system. Some sensitive points in the relief chain need more security than others, e.g., airports and seaports where aids enter the country and distribution centres so they are not stolen. Furthermore, aid in transit might also need close protection depending on the areas they must transit to reach their destinations or distribution points. Protection for non-military personnel is also an issue MF are usually allocated during HROs.
- Humanitarian interventions: they are launched to gain humanitarian access to an at-risk population when the host nation is enable or refuses to take action to alleviate human suffering or protect the local population. This type of intervention is a combat oriented operation intended to provide protection to the affected population and humanitarian aid workers by establishing favorable security conditions to HR activities.
- Protection of refugees and displaced people: this activity involves constructing and maintaining camp to concentrate individuals to ensure their safety. Security may be provided for the camp during the whole humanitarian crisis, or during specific periods corresponding to the return of refugees to their places of origin.

- Restoration of civil infrastructures: military resources are very often dedicated to the repair of some sensitive areas to guarantee operational flexibility of the ongoing HROs.

2.3 Military and humanitarian relief mission cycles

In this section, we review and compare some military deployment phases during classical and humanitarian missions.

Table 1: *Military activities in support of HROs*

Activity	Description
Field Engineering	Provide general military engineering capabilities, e.g., bridge construction for vehicles and/or pedestrian
Latrine Construction	Construct latrines to prevent the spread of disease, and ensure a hygienic disposal of human faeces
Road/airfield Construction	Prepare and conduct road/airstrip repair/construction to improve existing transportation systems
Training Mine Awareness/Clearing	Provide mine awareness/clearing training support to population and/or HR personnel
Water Treatment and Purification	Operate water purification equipment to provide potable water
Field Hospital	Provide full range of military medical support in austere environment
Radio and Satellite Communication	Establish a radio communication system to support information exchange within the area of operations, and satellite communication to support information exchange both within and out of the area of relief operations
Fixed Wing Strategic Airlift	Provide strategic airlift of humanitarian goods/cargo and the transportation of emergency personnel and equipment to the crisis area
Tactical Support Phase	Provide personnel, vehicles and communications equipment to support a filed mission headquarters
Fixed Wing/ Helicopter Theatre Airlift	Provide regional airlift (short-haul) capability for delivery of personnel, equipment, and/or humanitarian cargo within the crisis region in coordination with the UN Air Operations Centre, local authorities and humanitarian organizations involved
Mine Clearing	Provide mine clearing services in support of HROs

2.3.1 Military mission

Table 2 presents a description of the standard MF mission phases. A typical mission includes five phases: warning, preparation, deployment, employment, and redeployment. During the warning phase, the MF gather relevant data and conduct mission analyses leading to decisions on the deploying force structure and tasks. The preparation phase starts when the Government gives a go ahead for the mission. Depending on the mission, units may train before they leave and a Theatre Activation Team 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 home bases and transported to the mission area. The employment phase is the main phase of the mission where the MF execute their assigned tasks. If the mission lasts more than six months, some personnel rotations are required. The logistics support role during this phase is to support rotations and to resupply the goods consumed during the mission to sustain the force. 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.

Table 2: *Military deployment phases*

Warning	Government asks for analysis of the potential operations profile.
Preparation	Units train for the mission's objectives according to the projected conditions. A theatre activation team 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 home and local suppliers.
Redeployment	All units and their equipments are moved back home, sold, donated, or disposed.

The actual timing of these phases can vary depending on the mission type. For example, within the CF, DART 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 six days, which is relatively long considering the fact that people rarely survive if not rescued within 72 hours. For other humanitarian crisis such as famine and extensive refugee movements, deployed MF units were operational between 7 and 19 days after the warning phase [15]. On the other hand, due to logistics requirements, more than a month would be required for the deployment, reception and preparation for a mission engaging a full battle group in a land-locked theatre.

2.3.2 Humanitarian relief mission

HROs are more spontaneous and less structured than military missions. The disaster response cycle is usually composed of a set of activities that are performed before, during, and after a disaster [16]. Such activities can be divided into three phases, each demanding different types of assistance, different requirements, and capabilities [2].

- Life saving phase: also called in the literature the ramp-up stage, it covers the first few days after the onset of the disaster. Getting access to the field and setting up operations as fast as possible is the highest main objective. During this phase, the military participates in traditional and non-traditional operations, e.g, search and rescue, medical assistance, delivery of water and emergency shelter, emergency engineering and communication support.

- Stabilization phase: also called the sustainment phase. During this phase agencies focus on implementing their programs, while cost and efficiencies gain importance. Activities such as delivery of food and medical aid, development of local capacities such as water and sanitation, and the construction of emergency shelters are among the activities aimed to stabilize the affected crisis areas.

- Recovery phase: also called the ramp-down phase, agencies are focusing on their exit strategy including transfer of operations to local actors. Rehabilitation and reconstruction activities aimed at community self-sufficiency and restoration of local/national governance are the ultimate activities of the disaster response cycle.

However, because the whole disaster response is a continuous cycle, these phases are very often undertaken concurrently. In response of any disaster, these phases are conducted to save and protect lives, though, most of these activities are conducted at the same time. In terms of operational performance the interesting part about the transition between the different phases is the shift in focus from speed to cost reduction. The life saving phase is driven by the urgency of the needs and high levels of uncertainty. The focus on speed and cost is usually not considered during this phase. Humanitarian agencies prioritize (during this phase) the need to get to the area, observe and assess how many resources are needed, and implement immediate solutions. Optimizing the cost of operations is usually considered in the last phase.

2.4 Cooperation and coordination in decision-making

Humanitarian relief environments may intrinsically engage multiple decision-makers and a variety of actors each with different missions, goals, capacity, and logistics capabilities (NGOs, JIMP, multinational coalition) that need to be explicitly coordinated in order to manage interdependencies (e.g., due to resource-sharing, task precedence or expertise constraint requirements). As reported in [17, 18], a variety of recent work and publications on

HROs recognize coordination as a key challenge. Multiple organizations at various levels may be concurrently working at a major disaster site. These entities must collaboratively set up suitable facilities and infrastructure and efficiently supply and service affected people in disaster zones. Congestion may seriously impact relief supply availability, as shown in the Gujarat earthquake case, in which a single airport with few officials, land vehicles, and warehouses represented the main entry point for 50 organizations delivering goods over a 10-day period [13]. Intrinsic contention for local commodities and service providers (e.g., sheltering, vehicle purchase/lease) dramatically conducted inflation rate up by an order of magnitude in comparison to normal conditions.

Competition between HR organizations to get most visibility first in order to obtain preferential resource access from public and private donors further emphasizes the need for better coordination and cooperation between different actors/echelons along the supply network (vertical), or over a given level/echelon (horizontal). Cases calling for better coordination needs are presented in more details in [19–21]. In [22], the nature of benefits that horizontal cooperation may bring to disaster relief logistic operations between humanitarian organizations, as well as the practical obstacles impeding the delivery of the expected payoff, are briefly reported. Accordingly, the authors contend that coordination between humanitarian organizations contributes to improving overall operation efficiency, as insufficient or sub-optimal coordination wastes resources or puts at risk valuable response time unnecessarily. Thereby, cost reductions expected through price stabilization and warehouse network decentralization for supply and capability pre-positioning are recognized as key potential benefits. However, important or additional gains may be anticipated for lead-time reductions, quality control and capacity assurance through consolidation and standardization of procurement volumes, logistics process streamlining and possible stock exchange between individual humanitarian organizations. As a result, horizontal cooperation expectations include increased company's productivity (e.g., decrease in empty hauling, better usage of storage facilities), cost reductions of non-core activities (e.g., organizing safety trainings, joint fuel facilities), purchasing cost reductions (e.g., vehicles, on-board computers, fuel, maintenance), cheaper, faster and higher quality of service (e.g., frequency of deliveries, geographical coverage, reliability of delivery times), and shorter response time.

Coordination may however be hindered by multiple impediments such as payoff distribution or reward sharing, implicit competition among similar HROs supply/service providers, organization dominance over others and unbalanced visibility. Organizations attitudes and positions toward military HROs may also induce competition, opportunity losses or credibility concerns. Further obstacles impacting coordination and cooperation between humanitarian organizations include organizations' mandates, organizational structure, advocated information technology, real and perceived competition between humanitarian contributors, and the timeliness and accuracy of information exchanged during HROs [22].

3 Military and Humanitarian Relief Logistics

In this section, we focus on HR logistics and highlight some aspects of the problem where the contribution of the military is of high value.

Humanitarian logistics is defined by Thomas [23] as "the process of planning, implementing and controlling the efficient, cost effective flow and storage of goods and materials as well as related information from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing, customs and clearance" [23]. In-theatre HROs, which include a variety of operation in the field (e.g., distribution of relief supplies) present multiple logistics aspects and challenges with limited communications and usually damaged transportation infrastructure. In such environments, MF have proven to be better placed to quickly deploy capabilities to conduct activities such as air and land transportation of aid, air drops, airport improvement and navigation aid, electricity generation infrastructure repair, and water purification.

The distribution of relief supplies in a typical HRO involving international actors is shown in Figure 1 [12]. In this configuration, supplies received from international and local/regional donors are transported and stocked in depots, via air or land routes then, distributed to LDCs. The supplies reach the beneficiaries by local distribution from the LDCs. Different classes of trucks and helicopters may be used to convey the different classes of commodities to the beneficiaries. This relief distribution network topology resembles closely to a military tactical logistics topology where LDCs and beneficiaries in the HR domain are replaced by forward operating bases and deployed troops, respectively [24].

3.1 Military and humanitarian supply chains

The particular needs for HROs have resulted in the development of emergency-relief organization networks. These networks involve UN agencies such as the World Food Programme (WFP), NGOs such as the Red Cross, Médecins Sans Frontières (MSF), CARE and Oxford Committee for Famine Relief (OXFAM), as well as governmental organizations (such as the Stabilization and Reconstruction Task Force (START) in Canada), but they rely heavily on MF support. One of their aims is to set up emergency logistics networks to minimize the response time by bringing relief quickly and to maximize the relief in the disaster zone. To be efficient in their activities, the involved organizations should coordinate their actions. Previous studies on such networks showed 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, previous researches indicated that no increased transportation or road building would allow evacuating the population in a timely

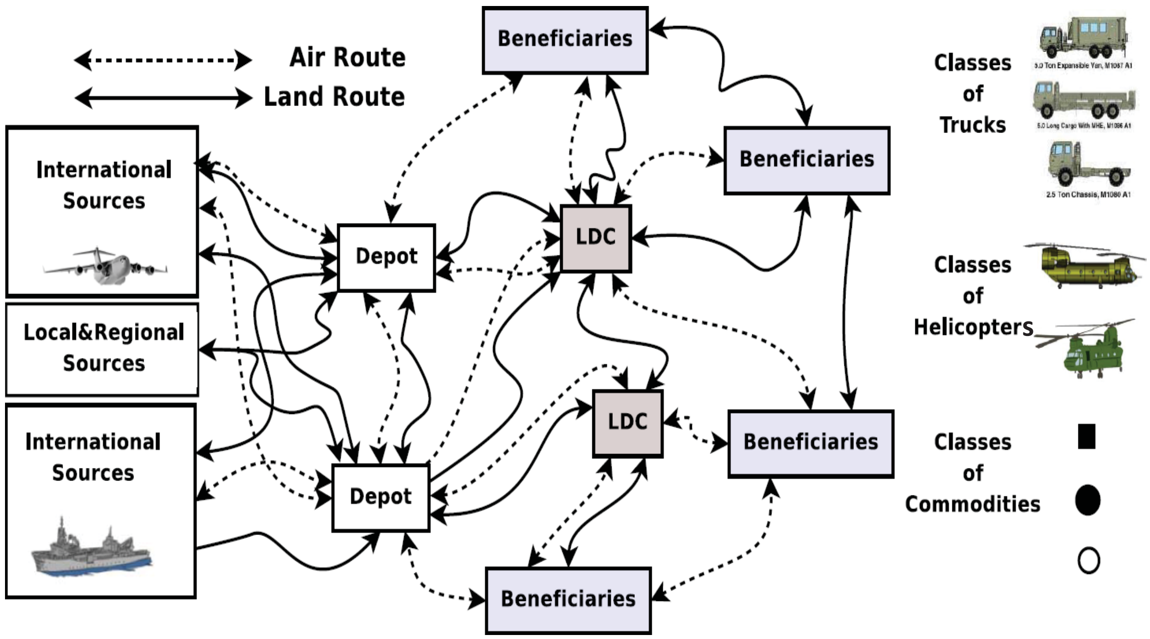

Figure 1: *Relief distribution topology*

manner" [25]. The current situation of the logistics function in the humanitarian sector is similar to logistics in the corporate sector in the 1980s. Indeed, the logistics function in the humanitarian sector is under-recognized, under-utilized and under-resourced [26].

Given the commitment of certain countries to continue contributing to emerging international conflicts, crisis and disasters, it seems clear that the global reach capabilities of these countries must be enhanced. International missions are complex and diverse, and it is important for their success to improve the overseas mission deployment speed and sustainability. Improving the global reach capabilities will improve the ability of the engaged countries in the humanitarian efforts to deploy quickly. A study examining the options of developing an overseas network of Operational Support Hubs (called also intermediate staging base) to improve the CF global reach is given by Ghanmi et al. [27]. Some larger countries have existing capabilities of this type, such as the United States military global en-route infrastructure, the United Kingdom legacy of permanent overseas bases, and France's African bases, are good examples. Theses countries also possess MF that are configured for rapid deployment. This option has the potential of improving deployment speed, sustainment efficiency, as well as the 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.

Regarding inventory management in HROs, a certain amount of insurance inventory needs to be kept in anticipation of future needs. However, 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 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.

3.2 Logistics problems in humanitarian relief operations

Although each crisis is unique in its details, most exhibit some similarities in the logistical response and the challenges they are facing. In the immediate aftermath of a disaster, military and humanitarian organization's staff must work under chaotic conditions. Local infrastructure such as roads, bridges, hospitals, and airports are often destroyed. Transport capacity are scarce. Local representatives of the population, to coordinate the relief efforts, are usually overwhelmed and cannot coordinate all the efforts. Within a disaster relief operation cycle, involved organizations are facing several logistics challenges. They are summarized as follows:

- Assessment: following a disaster, usually within a few hours, humanitarian organizations send assessment teams to assess the needs of the afflicted population in terms of health care, water and nutrition. Because this information is required within very short time and the chaotic conditions following directly the disaster, deployed logisticians estimate the needs based on rough estimation of the numbers of beneficiaries that may change drastically as new information emerges. MF are not usually involved in this step. During this phase, logisticians also select potential locations for installing crisis infrastructure including field hospitals, temporary depots, and distribution centres.

- Planning of operations: in order to provide effective relief, there is a critical challenge inherent to coordination of the relief distribution operations with other relief activities, such as infrastructure repair and construction, e.g., field hospitals. Several parameters need to be taken into consideration during this step, such as weather, safety issues, and the nature of the disaster.

- In-theatre operations: once supplies arrive at the local port of entry, the challenge of distributing them to the needy population becomes an issue. Given the uncertainty characterizing the demands, the number and distribution of beneficiaries, providing effective and fair relief support is not guaranteed with the lack of accurate information. Furthermore, because of the limited available resources, e.g., transportation assets and storage capacity, conducting in-theatre operations becomes a hard planning and scheduling problem. In this phase, MF have a long history of providing valuable assistance to afflicted people as well as to other relief agencies.

- Coordination with other HR actors: in some relief operations, hundreds of organizations are involved to set up facilities and infrastructure, distribute supplies and save people. However, due to the difficulty in coordinating the activities of all these agencies, several problems may appear at different levels during the relief activities. Problems that may result from the lack of coordination efforts are: unfair and inefficient distribution of supplies and congestion in the distribution chain. These problems are mainly due to the non-uniform distribution of relief agencies over the disaster area, which creates unfair distribution of supplies with some congested areas and some other less covered. As happened during the Gujarat earthquake when a single airport with few officials, transportation assets and warehouses served as the entry point for more than 50 organizations flying in supplies over a period of 10 days [13].

Facing such unpredictable conditions and hard coordination and planning problems, logisticians continually need to create new strategies to overcome these obstacles. In HROs, logisticians must get the right goods, to the right place, at the right time, within the limits of the budget, although at the very beginning they do not know exactly what they need, where and when they need it.

3.3 Planning factors in humanitarian relief logistics

In the planning process of HROs, a number of measures and constraints should be considered to achieve effective logistics planning:

- Timeliness: to be effective, a relief support needs to get on-time to its beneficiaries in order to save lives. This is especially true during the period directly following the disaster.

- Budgetary constraints: perceived aids from donors and governments do not match the required need of afflicted population. HR organizations involved in HROs need to target objectives reachable with their allocated budgets.

- Fairness in supply delivery: depending on its definition, fairness is usually intended to equally help afflicted people without any discrimination.

4 Military Relief Distribution Scheduling : Mathematical Models

This section is concerned with developing mathematical models for designing HR network topology and scheduling relief distribution in a large-scale natural and/or complex disaster. The focus is on developping efficient ways to schedule relief distribution in the fields. Although we tailored the optimization models to military relief distribution missions (mainly using military assets), they can be used in any humanitarian relief scheduling operations by relaxing and/or adding some operational constraints to meet the new needs. In this study, we assume that MF are in charge of logistics planning for reliefs distribution. Therefore, the commander has possession of the available logistics resources that he can use in the execution of the established relief plan (i.e., a centralized scheduling approach).

4.1 Literature review

Several aspects of the planning and scheduling of supply distribution problem have been addressed in the literature with different assumptions, objectives, and constraints. The collaboration between military and humanitarian actors is discussed in [28]. In this section, we discuss key papers addressing some problems related to logistics distribution in HROs. An overview and classification of papers discussing the disaster relief operations can be found in [16, 29, 30].

The optimization problem in relief distribution and scheduling is to find the optimal loading and routing patterns of transportation assets subject to time schedule, delivery delay, transportation capacity, safety and security in the network, cost budget, storage capacity, and fairness in distribution of commodities constraints. This problem can be seen as a particular case of the classical Vehicle Routing Problem (VRP) and Multiple Bin Packing Problem (MBPP), which have been proven NP-hard [2] problems [31–33].

Research papers in relief distribution can be classified into two categories involving utilitarian and egalitarian policies, respectively. In egalitarian policies, the objective is to maximize equality of some metrics such as delivery time and amounts of delivered commodities. While in utilitarian policies, the objective is to maximize or minimize a global metric without requiring equality in distribution of relief supplies. Objectives that are utilitarian in delivery of relief support can be found in a number of research papers including [34–38]. In [34], Campbell et al. focused on the service time and proposed two objective functions: minimizing the maximum arrival time and minimizing the sum of arrival times of supplies. Therein, each demand location is visited exactly once, and demands are satisfied with one

[2]Non-deterministic polynomial-time hard. The optimization problem, "what is the optimal solution of the loading and routing problem in our tactical logistics problem?", is NP-hard, since there is no easy way (polynomial-time algorithm) to determine if a solution is optimal.

visit. Equity in the delivery time was not considered in this work. Knott [38] proposed an Integer Linear Programming (ILP) model to find the number of trips a vehicle has to make in order to maximize the amount of delivered commodities while minimizing the transportation cost. In Nolz et al. [35], the focus is on minimization of the total amount of unsatisfied demands while minimizing the latest arrival time at each destination. This last metric is an egalitarian measure of delivery speed. In [39], a modeling framework to address the crew assignment, and routing of helicopters during the initial response phase of disaster management is proposed. The authors developed ILP models to minimize the number of tours each helicopter performs and optimize the assignment of pilots to helicopters. A solution approach based on heuristics was developed as the size of the resulting ILP models is huge and no exact solution method was proposed to solve the models. Other research papers with utilitarian objectives focused on minimizing the amount of unsatisfied demands [37, 40–42], on minimizing logistics costs [41, 43–45], and on minimizing completion delay [39, 46].

In HROs, the needs of beneficiaries very often exceed the available relief supplies, and involved humanitarian organizations have to choose allocation strategies to impartially distribute the aids according to the needs. In order to ensure a fair distribution of supplies, equity is a critical metric in HROs [12]. There are some relief distribution models using egalitarian policies to maximize the equality of some measures. Huang et al. [36] extended the work of Campbell et al. in [34] by weighting the arrival time by the amount of commodities required at each destination. Therein, three metrics are introduced to measure equity in relief distribution. The first two are deviation-type equity metrics that measure the spread in service level across destinations, and the third calculates the equity in delivery time. A numerical study on small instances, in which it is possible to obtain an optimal solution, was conducted and heuristics were developed to solve large instances. In [11], the authors consider the fairness problem under the intermediate facility location problem in distributing supplies from a set of supply sources to demand points. A multi-period multi-objective model is developed where the objective is minimizing the logistics cost, travel time, and maximizing the minimum service satisfaction among demand points. In [12], a joint model of routing and supply allocation in distributing multiple types of relief supplies is proposed. The authors minimize the maximum unsatisfied demand percentage over demand locations over a planning horizon.

4.2 Assumptions and motivation

In this work, we consider the following characteristics and assumptions in modeling of the different aspects of the relief distribution problem:

- Two modes of transportation: air and land;
- Multiple classes of supplies;

- Transportation fleet of limited size: limited number of helicopters and trucks;
- Transportation assets may be pre-positioned at intermediate locations to increase the effectiveness of the distribution system;
- Storage capacity: depots are of limited capacities and can receive different quantities of each class of supplies;
- Land transportation routes are not necessarily safe during all the scheduling horizon;
- A security budget is available to secure some land routes during some scheduling intervals;
- Some beneficiaries can be reached only by air or land, or both;
- Total demand for relief supplies of each class of commodities is higher than the offer;
- Supplies are required within different time windows and may be delivered within different time windows; and
- Multiple visits are required to each demand point to deliver all required commodities;

Given that, the needs of the different classes of commodities are not the same during the different phases of the disaster relief cycle, and the stages are very often undertaken concurrently, we develop a multi-period scheduling approach to effectively plan the overlapping of the periods and optimize the sharing of the limited resources, e.g., storage and transportation capacities.

4.3 Mathematical Description of Models

A typical in-theatre relief topology is shown in Figure 1. The entry points of goods are an airport, a seaport, and a local/regional source, all located in safe areas. The relief time horizon is divided into multiple periods of equal durations. The duration of each period is assumed to correspond to the time required to deliver commodities from one location to the next in the relief topology. Given that we have a limited number of transportation assets and storage capacity at intermediate locations, and that different commodities may be required within different time periods, we develop an optimization method that shares the logistics resources (transportation assets and storage capacities) and pre-positions transportation assets and commodities to anticipate future needs of beneficiaries.

Our model extends the classical Capacitated Vehicle Routing Problem with Time Window (CVRPTW) by allowing transshipment and change in transportation mode at intermediate nodes during transportation. Furthermore, we allow delivery of commodities within different time periods and allocate different rewards to the different deliveries within each time period. This variant of the multi-time period delivery is used because it models more accurately the reality of the HR environment and distribution model. A variety of solutions based on heuristics, and exact methods have been developed for different versions of the problem [32, 47–50]. With the objective to develop a flexible modeling and solution approaches that would scale in large relief support topology, we adopt a Column Generation (CG) decomposition approach. CG is an efficient optimization method for solving large scale Linear Programs (LPs) and its performance unfolds in solving ILP problems [32, 51].

4.4 Column generation decomposition methodology

Our CG decomposition approach is based on the separation between the design and optimization of relief plans. A relief plan $p \in \mathcal{P}$ is a combination of transportation assets, trucks and helicopters, distributed along the network routes and pre-positioned at some nodes to transport different amounts of commodities to different beneficiaries during different time periods. Figure 2 presents an example of a relief plan. The distribution of transportation assets in a relief plan is performed in a way that sends *at most* one transportation asset during each time slot on each route. As illustrated in Figure 2: from Main Depot to Depot 1 are sent on the same route a helicopter and a truck during time slot T_1 and T_2, and during the same time slot T_1 a helicopter and a truck but on two different routes from Main Depot to Deport 1 and Depot 2.

The different commodities (represented by filled and non-filled circle in Figure 2) and transportation assets could be either pre-positioned at intermediate nodes during some time slots, e.g., at Depot 1 during time slot T_2 and at Depot 2 during time slots T_2 and T_3, or on the road to the different destinations. The transportation assets are re-routed back to the main depot after delivering the commodities.

This decomposition is elaborated to address the computation of the operating cost and to break the symmetry in the ILP model due to the similitude of the trucks and helicopters of the same classes. To meet the demands of each destination, we assumed that multiple visits are required to deliver the whole demands. Therefore, multiple relief plans may be required to meet the whole demand of any destination. By doing so, we divide the whole scheduling problem into subscheduling problems of limited sizes involving each a limited number of transportation assets and commodities. As the number of involved assets in each subproblem cannot exceed the number of routes, the size of a scheduling subproblem in this case is defined by the number of routes not the fleet size.

In order to set up the mathematical models, we define the following sets and parameters:

Sets:

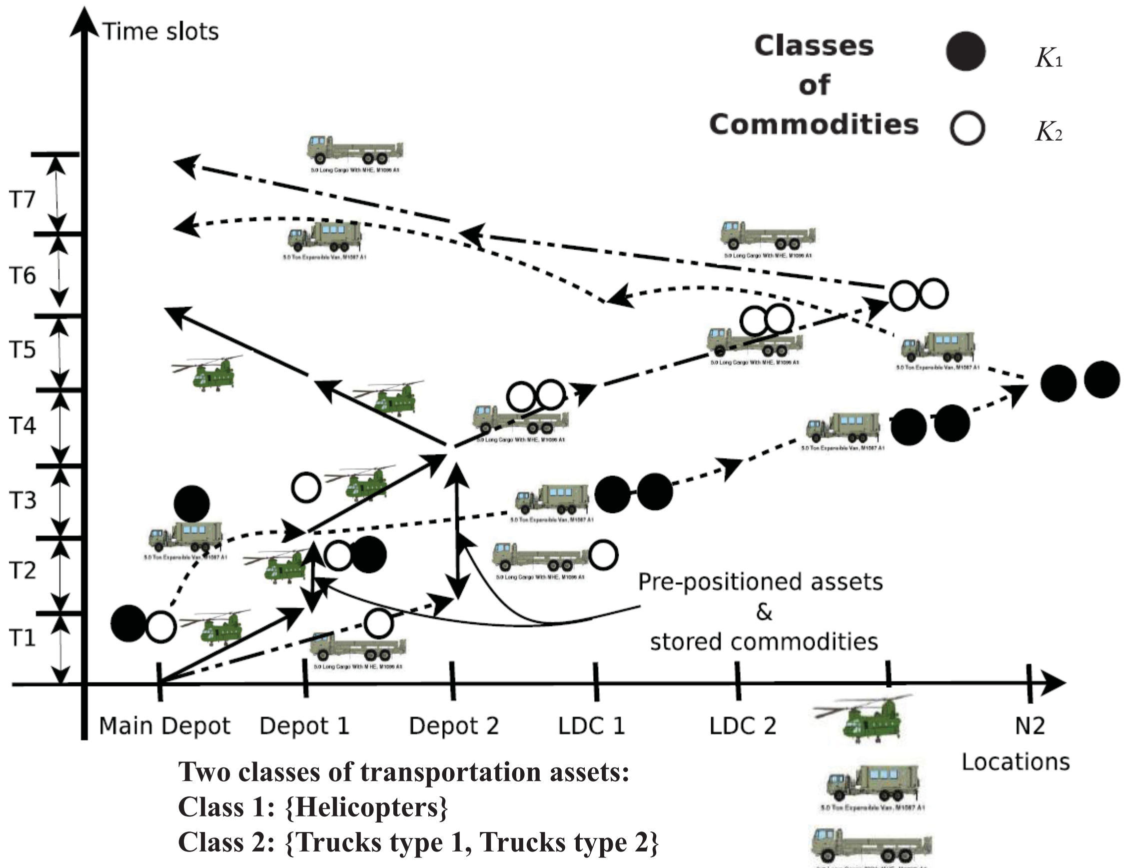

Figure 2: *A relief plan*

$\mathcal{P}$	relief plans, indexed by p,
$\mathcal{M}$	intermediate locations, including depots, LDCs, indexed by m,
$\mathcal{N}$	destinations (beneficiaries), indexed by n,
$\mathcal{R}$	routes, including land and air routes, indexed by r,
$\mathcal{V}$	classes of transportation assets, trucks and helicopters, indexed by v,
$\mathcal{K}$	classes of commodities, indexed by k,
$\mathcal{T}$	time slots, indexed by t,
$\omega^+(m)$	set of outgoing routes from location $m \in \mathcal{M}$, similarly $\omega^+(n)$ for $n \in \mathcal{N}$,
$\omega^-(m)$	set of incoming routes to location $m \in \mathcal{M}$, similarly $\omega^-(n)$ for $n \in \mathcal{N}$.

Parameters:

A_v^t	number of available trucks of class v during time slot t,
B_v	bulk capacity of transportation assets of class v (number of units),
$C_{v,r}^t$	operating cost of a transportation asset of class v on route r during time slot t (\$),
C_p	operating cost of relief plan p. It is equal to the sum over the cost of each transportation assets used on the different routes within the relief plan p (\$),
d_n^k	maximum amount of commodities of class k (offer) that could be transported to destination n,
D_r	distance of route r (km),
H_v^t	number of available helicopters of class v during time slot t,
I_m	cost of building a depot at location m,
O_m	storage capacity (number of units) of location m,
Q_v	payload capacity of transportation assets of class v (ton),
S_v	cruising speed of transportation assets of class v (km/h),
$U_{n,k}^t$	$\in \mathbb{R}_+$ value of the utility function of delivering commodities of class k to destination n within time slot t,
U_p	value of the utility function within the whole relief plan. It is equal to $\sum_{n\in\mathcal{N}}\sum_{k\in\mathcal{K}}\sum_{t\in\mathcal{T}} U_{n,k}^t$,
W_k	weight of one unit of commodity of class k (ton),
$(a_v^t)_p$	number of trucks of class v used during time slot t within relief plan p,
$(E_m)_p$	binary parameter equal to 1 if node m is used in relief plan p,
$(F_{v,r}^t)_p$	equal to 1 if a transportation asset of class v is used on route r during time slot t within relief plan p, 0 otherwise,
$(h_v^t)_p$	number of helicopters of class v used during time slot t within relief plan p,
$\left(Q_{m,k}^t\right)_p$	number of commodity units of class k stored at node m during time slot t within relief plan $p \in \mathcal{P}$,
$\left(Q_{n,k}^t\right)_p$	number of commodities units of class k received at destination n during time slot t within relief plan $p \in \mathcal{P}$.

Index p is dropped from variables $\left(Q_{m,k}^t\right)_p$ and $\left(Q_{n,k}^t\right)_p$ in the pricing problem.

Given these parameters and variables, a relief plan p can be formally defined as a set of $(|\mathcal{K}|+3)-$tuple where $|\mathcal{K}|$ is the size of the set of classes of commodities and the 3 other elements refer to the route identity, time interval identity, and transportation assets class identity, respectively. A relief plan is defined formally as a set of $(|\mathcal{K}|+3)-$tuple of the following form: route r, time interval t, one transportation asset of class $v_i(i = 1,\dots,|\mathcal{V}|)$, amount of commodities of classes $k_i(i = 1,\dots,|\mathcal{K}|)$. The key identity of each $(|\mathcal{K}|+3)-$tuple is the route identity and time interval identity. A relief plan may have several $(|\mathcal{K}|+3)-$tuples with the same route or same time interval but never the same route and time interval identities. The motivation behind this kind of decomposition is, in addition to practical complexity reduction, to ease the computation of the operating cost as it is a function of the used transportation asset (operating cost and cruising speed) and the distance of the used routes (see below for a mathematical formula for the operating cost computation).

The operating cost model

In the computation of the cost of each relief plan (C_p), we consider the operating cost of each of its transportation assets which is given as follows:

$$Operating\,cost\,(\$) = \frac{Hourly\,Cost\,Rate\,(\$/h) \times Distance\,(km)}{Cruising\,Speed\,(km/h)} \tag{1}$$

The selected transportation assets within each relief plan will ensure delivery of parts of the supplies to some destinations. It is a combination of relief plans that are needed to build up a global relief support strategy. In our CG approach, the optimization and design of relief plans are performed by the master and pricing problems, respectively. These two models are presented below.

4.4.1 Master model

In the master model, we optimize the selection of relief plans $p \in \mathcal{P}$. We define the following variables:

Z_p $\in \mathbb{Z}^+$is the number of copies of relief plan p. These variables allow us to construct global relief strategies by combining similar copies of the same relief plan. For example, if within a relief plan p a truck of class v is used on route r during time slot t and $Z_p = np\,(\in \mathbb{Z}^+)$, then, np similar trucks of class v will be used during the same time interval in the global support strategy on route r by combining np copies of relief plan p.

L_m is a binary variable to capture if a depot is installed at location m.

The objective function:

The objective function is composed of three terms: maximize the utility function of the relief plans, i.e., the delivery of commodities (during specific time periods) to beneficiaries; minimize the operating cost of the selected relief plans, i.e., the operating cost of the selected transportation assets in each relief plan; and minimize the capital cost of installing depots. The expression of the objective is given as follows:

Maximize:

$$z^{\text{MASTER}} = \overbrace{\sum_{p\in\mathcal{P}} U_p\, Z_p}^{Utility} - \overbrace{\sum_{p\in\mathcal{P}} C_p\, Z_p}^{Operating\ cost} - \overbrace{\sum_{m\in\mathcal{M}} I_m\, L_m}^{Capital\ cost}$$

where the first term is a real value measuring the whole utility of delivering the commodities to their destinations, and the second and third are dollar costs.

Using the above pre-defined parameters, the expression of the reduced cost can be re-expressed as follows:

$$z^{\text{MASTER}} = \sum_{p\in\mathcal{P}}\sum_{n\in\mathcal{N}}\sum_{k\in\mathcal{K}}\sum_{t\in\mathcal{T}}(U^t_{n,k}\, Q^t_{n,k})_p\, Z_p - \sum_{p\in\mathcal{P}}\sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}}\sum_{t\in\mathcal{T}}(C^t_{v,r} F^t_{v,r})_p\, Z_p - \sum_{m\in\mathcal{M}} I_m\, L_m. \tag{2}$$

Constraints:

- Location constraints of the depots.

$$\varepsilon \sum_{p\in\mathcal{P}} (E_m)_p Z_p \leq L_m \qquad m \in \mathcal{M} \tag{3}$$

  where $\varepsilon \ll 1$.

  These constraints are used to capture whether or not a depot is installed at location m. If any relief plan p is routing assets through location m then, a depot is considered as installed at m.

- Storage capacity constraint of the depots.

$$\sum_{p\in\mathcal{P}} \Big[\sum_{k\in\mathcal{K}} Q^t_{m,k}\Big]_p Z_p \leq O_m \qquad m \in \mathcal{M}, t \in \mathcal{T} \tag{4}$$

  These constraints are used to set up an upper bound on the storage capacity of each depot $m \in \mathcal{M}$. The used storage capacity by all relief plans can not exceed the specified value O_m.

- Offer and demand constraints.

$$\sum_{p\in\mathcal{P}} \Big[\sum_{t\in\mathcal{T}} Q^t_{n,k}\Big]_p Z_p \leq d^k_n \qquad n \in \mathcal{N}, k \in \mathcal{K} \tag{5}$$

$$\sum_{p\in\mathcal{P}} \Big[Q^t_{n,k}\Big]_p Z_p \leq \overline{Q^t_{n,k}} \qquad n \in \mathcal{N}, k \in \mathcal{K}, t \in \mathcal{T} \tag{6}$$

$$\sum_{p\in\mathcal{P}} \Big[Q^t_{n,k}\Big]_p Z_p \geq \underline{Q^t_{n,k}} \qquad n \in \mathcal{N}, k \in \mathcal{K}, t \in \mathcal{T} \tag{7}$$

Constraints (5) set up an upper bound on the number of commodities delivered to each destination n (offer) during each time period $t \in \mathcal{T}$. Constraints (6) and (7) are used to set up an upper bound $\overline{Q^t_{n,k}}$ and lower bound $\underline{Q^t_{n,k}}$ on the number of required commodities at each destination n during each time period t.

- Fleet size constraints.

$$\sum_{p \in \mathcal{P}} (a^t_v)_p Z_p \leq A^t_v \qquad v \in \mathcal{V}, t \in \mathcal{T} \tag{8}$$

$$\sum_{p \in \mathcal{P}} (h^t_v)_p Z_p \leq H^t_v \qquad v \in \mathcal{V}, t \in \mathcal{T} \tag{9}$$

These constraints are used to set up an upper bound on the number of available trucks and helicopters of each class $v \in \mathcal{V}$ during each time slot $t \in \mathcal{T}$, respectively.

4.4.2 Pricing model

The pricing problem, which is used to generate a promising relief plan each time it is run, corresponds to the maximization of the reduced cost of the restricted master problem subject to a set of relief plan design constraints. The expression of the reduced cost ($\overline{C}_p$) of a relief plan p is given as follows:

$$\begin{aligned}\overline{C}_p = & \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} U^t_{n,k} Q^t_{n,k} - \sum_{v \in \mathcal{V}} \sum_{r \in \mathcal{R}} \sum_{t \in \mathcal{T}} C^t_{v,r} F^t_{v,r} \\ & - \sum_{m \in \mathcal{M}} \varepsilon E_m (\theta_1)_m \\ & - \sum_{m \in \mathcal{M}} \sum_{t \in \mathcal{T}} \Big[\sum_{k \in \mathcal{K}} Q^t_{m,k} \Big] (\theta_2)^t_m \\ & - \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} Q^t_{n,k} \big(\theta_3 - \theta_4\big)^t_{n,k} \\ & - \sum_{v \in \mathcal{V}} \sum_{t \in \mathcal{T}} a^t_v (\theta_3)^t_v \\ & - \sum_{v \in \mathcal{V}} \sum_{t \in \mathcal{T}} h^t_v (\theta_4)^t_v \end{aligned} \tag{10}$$

where $\theta_i (i = 1,2,3,4)$ are the values of the dual variables associated with constraints (3), to (9). $E_m, F^t_{v,r}, Q^t_{m,k}, Q^t_{n,k}, a^t_v, h^t_v$ which were parameters in the master problem become variables in the pricing problem. In addition, we define the following variables of the pricing problem:

$y^t_{n,r,k}$ for each destination $n \in \mathcal{N}$, class of commodity $k \in \mathcal{K}$, route $r \in \mathcal{R}$, and time slot $t \in \mathcal{T}$ is the amount of commodities of class k transported to destination n along route r during period of time t.

$x^t_{v,m}$ number of trucks of class v pre-positioned at location m (including destinations) during time slot t.

$g^t_{v,m}$ similarly to $x^t_{v,m}$, is the number of helicopters of class v pre-positioned at location m during time slot t.

We define the constraints of the pricing problem as follows:

- For each $r \in \mathcal{R}, t \in \mathcal{T}$:

$$\sum_{v \in \mathcal{V}} F^t_{v,r} \leq 1 \tag{11}$$

$$\sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{K}} W_k \, y^t_{n,k,r} \leq \sum_{v \in \mathcal{V}} Q_v \, F^t_{v,r} \tag{12}$$

$$\sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{K}} y^t_{n,k,r} \leq \sum_{v \in \mathcal{V}} B_v \, F^t_{v,r} \tag{13}$$

  Constraints (11) state that at most one transportation asset (helicopter or truck) of a given class v could be used on route r during time slot t. Constraints (12) and (13) are payload and bulk transportation capacity constraints, respectively. They set up upper bounds on the transported assets of all classes.

- For each $n \in \mathcal{N}, k \in \mathcal{K}, r \in \mathcal{R}, t \in \mathcal{T}$

$$y^t_{n,k,r} \leq \psi \sum_{v \in \mathcal{V}} F^t_{v,r} \tag{14}$$

  where $\psi \in \mathbb{Z}^+$ is an arbitrary large number.

  Constraints (14) state that route r is used during time period $t \in \mathcal{T}$ to transport commodities of class k to destination n only if there is a transportation asset on r.

- For each $n \in \mathcal{N}, k \in \mathcal{K}, m \in \mathcal{M}, t \in \mathcal{T}$

$$Q^t_{m,k} = Q^{t-1}_{m,k} + \sum_{n \in \mathcal{N}} \sum_{r \in \omega^-(m)} y^{t-1}_{n,k,r} - \sum_{n \in \mathcal{N}} \sum_{r \in \omega^+(m)} y^t_{n,k,r} \tag{15}$$

  Constraints (15) are used to record the amount of commodities of class k stored at each location m during each time period t. This amount is equal to what was at m during previous time period $m-1$ plus the difference between the received amount during the previous period and the expedited amount during the same time period.

- For each $n \in \mathcal{N}, k \in \mathcal{K}, t \in \mathcal{T}$

$$Q^t_{n,k} = \sum_{r \in \omega^-(n)} y^{t-1}_{n,k,r} \tag{16}$$

Constraints (16) are used to record the amount of commodities of class k received at destination n during time slot t.

- For each $v \in \mathcal{V}, m \in \mathcal{M}, t \in \mathcal{T}$

$$x^t_{v,m} = x^{t-1}_{v,m} + \sum_{r(land) \in \omega^-(m)} F^{t-1}_{v,r} - \sum_{r(land) \in \omega^+(m)} F^t_{v,r} \tag{17}$$

$$g^t_{v,m} = g^{t-1}_{v,m} + \sum_{r(air) \in \omega^-(m)} x^{t-1}_{v,r} - \sum_{r(air) \in \omega^+(m)} x^t_{v,r} \tag{18}$$

Similarly to constraints (15), constraints (17) and (18) are used to record pre-positioned trucks and helicopters, respectively.

- For each $k \in \mathcal{K}, m \in \mathcal{M}$

$$\sum_{n \in \mathcal{N}} \sum_{t \in \mathcal{T}} \Big[\sum_{r \in \omega^+(m)} y^t_{n,k,r} - \sum_{r \in \omega^-(m)} y^t_{n,k,r} \Big] = 0 \tag{19}$$

Constraints (19) are used to ensure relief flow conservation at each intermediate location for each class of commodities.

- For each $v \in \mathcal{V}, m \in \mathcal{M} \cup \mathcal{N}$

$$\sum_{t \in \mathcal{T}} \Big[\sum_{r \in \omega^+(m)} x^t_{v,r} - \sum_{r \in \omega^-(m)} x^t_{v,r} \Big] = 0 \tag{20}$$

$$\sum_{t \in \mathcal{T}} \Big[\sum_{r \in \omega^+(m)} h^t_{v,r} - \sum_{r \in \omega^-(m)} h^t_{v,r} \Big] = 0 \tag{21}$$

Constraints (20) and (21) are used to ensure transportation assets flow conservation at each location $m \in \mathcal{M} \cup \mathcal{N}$, respectively.

- For each $v \in \mathcal{V}, t \in \mathcal{T}$ correspondence between master and pricing variables

$$a_v^t = \sum_{m \in \mathcal{M}} x_{v,m}^t + \sum_{r(land) \in \omega^+(m)} F_{v,r}^t \tag{22}$$

$$h_v^t = \sum_{m \in \mathcal{M}} g_{v,m}^t + \sum_{r(air) \in \omega^+(m)} F_{v,r}^t \tag{23}$$

  Constraints (22) and (23) are used to capture the number of trucks and helicopter used in the current relief plan. The number of trucks (respectively helicopters) used in the current relief plan is equal to the number of trucks (respectively helicopters) on the road plus those pre-positioned at the different locations.

- For each $m \in \mathcal{M}$

$$E_m \geq \varepsilon \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{K}} \sum_{r \in \omega(m)} \sum_{t \in \mathcal{T}} y_{n,k,r}^t \qquad \varepsilon \ll 1 \tag{24}$$

  Constraints (24) are used to capture if a potential location of a node is used in the routing of assets. If so, the variable E_m will be set to 1 to specify that by the current plan a node is required at the specified location.

To the best of our knowledge, this model is the first to address all these practical aspects of the relief distribution problem and to propose a CG modeling approach to scale the solution algorithm.

5 Computational Results

This section is divided into two subsections to illustrate the proposed methodology. In the first subsection, we assess the performance of the proposed CG algorithm. In the second, we simulate a HR environment and analyze the results obtained by the proposed solution algorithm.

5.1 Algorithmic performance assessment

The CG is extended with a Branch-and-Bound (B&B) algorithm to generate an integer solution once the optimal LP is obtained. The B&B algorithm operates on the so-far generated columns in the CG algorithm. Table 3 presents the results obtained using the CG algorithm involving 12 different patterns of demand generated for different HROs. The distributions of the required demands are randomly generated within approximated intervals. Therein, we measure the value of objective function of the optimal linear solution Z_{LP}, the integer solution Z_{ILP} (both numerical values), the integrality gap[3] between them (%), and the running time (in seconds) until the final integer solution (Z_{ILP}) of the CG. Within these 12 instances, we relaxed the number of transportation assets constraints (constraints 8 and 9) by setting large bounds. Furthermore, for the multi-delivery time, we set a similar utility of delivering commodities during different time periods.

Table 3: *Performance measurements*

	z_{LP}	z_{ILP}	Gap (%)	Time (sec)
1	186616	182505	1.8	2064
2	135733	132153	1.3	946
3	736384	713911	3.0	3478
4	193913	189795	2.1	829
5	237549	228278	3.9	384
6	140574	137090	2.4	2295
7	213241	209938	1.5	2913
8	185949	183436	1.3	1580
9	165961	164859	0.6	1302
10	165857	164692	0.7	1153
11	138704	137652	0.7	564
12	166007	164744	0.7	3183

The obtained results show how effective is the CG approach in obtaining optimal continuous solutions and deriving good integer ones. The integer solutions obtained by extending

[3] Is the difference between the LP and ILP solution values.

the CG algorithm with a B&B show a very low integrality gap in [0.6%, 3.9%]. The running time of all performed experiments is less than one hour and is within the interval of time [384, 3183] seconds.

5.2 A humanitarian relief scenario

In this section, we demonstrate the proposed methodology by using an hypothetical example of scheduling of reliefs distribution in HROs.

5.2.1 The logistics network

The illustrative topology in Figure 3 shows a relief distribution topology where the different locations are chosen to cover the scattered populations. While the locations of the LDCs are defined to cover the beneficiaries, the potential locations of the depots are identified for selection. In this scenario, beneficiaries are aggregated into destination points and delivered relief commodities through depots and LDCs. The arrows starting from the *Depots* ending at the *LDCs* indicate the direction of relief flow. For example, Depot 1 can be used to distribute reliefs to LDC_i $(i = 1, \ldots, 4)$. We assume that the entry points of supplies (Airport/Seaport of Disembarkation (A/S)POD and local sources) are collocated within the same place from which commodities are transported to LDCs through the depots.

Table 4 illustrate the capital cost (renting or construction) of the potential depots in Figure 3 with the storage capacity of each.

Table 4: *Depots: capital cost and storage capacity*

Depots	Capital cost (renting, constructing) ($)	Storage capacity (pallets)
1	100,000	60
2	90,000	40
3	90,000	40
4	100,000	60

Regarding the transportation fleet, we use two classes of helicopters: CH-147D Chinook and CH-146 Griffon, and two classes of trucks: Medium Logistic Vehicle Wheeled (MLVW), and Heavy Logistic Vehicle Wheeled (HLVW). These assets are characterized by their physical (payload and bulk capacities) and operational (hourly cost, range, and cruising-speed) characteristics [24] shown on Table 5. Furthermore, we assume a relief planning horizon of five days divided into ten time slots.

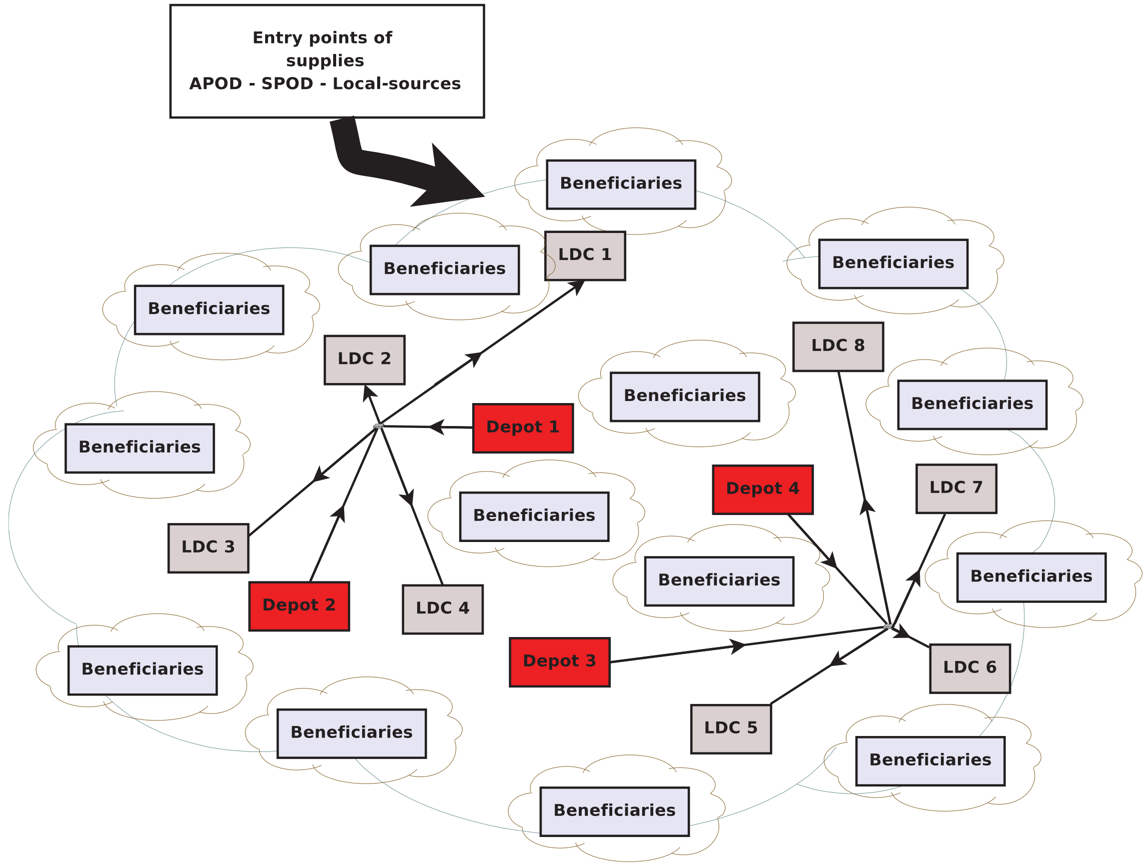

Figure 3: *A relief distribution topology*

5.2.2 Commodities, demands, and offers

From a transportation requirement point of view, we grouped our commodities into three classes: general (e.g., food, clothing, medical material), refrigerated (e.g., fresh food, rations, medical material), and construction materiel, referred to by K_1, K_2, and K_3, respectively. In this study, we suppose that commodities are packed into pallets (standard transportation units) of similar size. The average weights of the pallets depend on their contained class of commodity and described as follows: general 1 Ton, refrigerated 0.5 Ton, and construction 1.5 Ton.

To approximate the needs of afflicted populations in our hypothetical model, we used some military forecasting logistics models [52]. These models have been used to estimate the demand in terms of number of pallets of a particular needed commodity for a particular population size. Different scenarios were simulated with different population sizes and needs over the scheduling horizon. Table 6 illustrates the distribution of the demands over the relief horizon. We support given (estimated) the demands of each destination (number of pallets) $\in [\min, \max]$ for each class of commodities during each time slot. In each case

Table 5: *Characteristics of classes of transportation assets*

		Capacity		Range (km)	Speed (km/h)	Cost per hour ($)
		Payload (Ton)	Bulk (#Pallet)			
Helicopters	CH-147D Chinook	12.2	8	800	220	8000
	CH-146 Griffon	1.9	1	550	200	5000
Trucks	MLVW-Cargo	5.0	4	536	90	442
	HLVW-Cargo	10.0	8	732	85	517

of Table 6 the min and max number of pallets of each class of commodities K_i required within the specified time slot are reported. The min and max amount of commodities of each class required by each destination and during each time slot are represented in the last column and line of Table 6, respectively.

Table 6: Demand pattern

Dst	K	Time-slots						Total
		1	2	3	4	5	6	
1	K_1	(5, 8)	(5, 8)	(5, 8)	(5, 8)	(5, 8)	(5, 10)	**(31, 50)**
	K_2	(5,10)	(5, 10)	(5, 6)	(5, 6)	(5, 8)	(5, 10)	**(30, 50)**
	K_3	(5, 6)	(5, 8)	(5, 6)	(5, 10)	(5, 10)	(5, 10)	**(30, 50)**
2	K_1	(3, 6)	(8, 15)	(6, 10)	(5, 8)	(5, 6)	(4, 5)	**(30, 50)**
	K_2	(5, 5)	(5, 15)	(5, 5)	(5, 7)	(5, 8)	(5, 10)	**(30, 50)**
	K_3	(5, 6)	(5, 8)	(5, 6)	(5, 10)	(5, 10)	(5, 10)	**(30, 50)**
3	K_1	(5, 8)	(5, 8)	(5, 8)	(5, 8)	(5, 8)	(5, 10)	**(32, 50)**
	K_2	(5,10)	(5, 10)	(5, 6)	(5, 6)	(5, 8)	(5, 10)	**(30, 50)**
	K_3	(5, 6)	(5, 8)	(5, 6)	(5, 10)	(5, 10)	(5, 10)	**(30, 50)**
4	K_1	(3, 6)	(8, 15)	(6, 10)	(5, 8)	(5, 6)	(4, 5)	**(31, 50)**
	K_2	(5, 5)	(5, 15)	(5, 5)	(5, 7)	(5, 8)	(5, 10)	**(30, 50)**
	K_3	(5, 6)	(5, 8)	(5, 6)	(5, 10)	(5, 10)	(5, 10)	**(30, 50)**
5	K_1	(5, 8)	(5, 8)	(5, 8)	(5, 8)	(5, 8)	(5, 10)	**(30, 50)**
	K_2	(5,10)	(5. 10)	(5, 6)	(5, 6)	(5, 8)	(5, 10)	**(30, 50)**
	K_3	(5, 6)	(5, 8)	(5, 6)	(5, 10)	(5, 10)	(5, 10)	**(31, 50)**
6	K_1	(3, 6)	(8, 15)	(6, 10)	(5, 8)	(5, 6)	(4, 5)	**(31, 50)**
	K_2	(5, 5)	(5, 15)	(5, 5)	(5, 7)	(5, 8)	(5, 10)	**(30, 50)**
	K_3	(5, 6)	(5, 8)	(5, 6)	(5, 10)	(5, 10)	(5, 10)	**(30, 50)**
7	K_1	(5, 8)	(5,8)	(5, 8)	(5, 8)	(5, 8)	(5, 10)	**(30, 50)**
	K_2	(5,10)	(5, 10)	(5, 6)	(5, 6)	(5, 8)	(5, 10)	**(30, 50)**
	K_3	(5, 6)	(5, 8)	(5, 6)	(5, 10)	(5, 10)	(5, 10)	**(31, 50)**
8	K_1	(3, 6)	(8, 15)	(6, 10)	(5, 8)	(5, 6)	(4, 5)	**(31, 50)**
	K_2	(5, 5)	(5, 15)	(5, 5)	(5, 7)	(5, 8)	(5, 10)	**(30, 50)**
	K_3	(5, 6)	(5, 8)	(5, 6)	(5, 10)	(5, 10)	(5, 10)	**(30, 50)**
Total		112/164	132/256	124/164	120/196	120/200	117/220	**728/1200**

Table 7 presents the offers of each class of commodities K_i versus the min and max amounts of demands of each class. After meeting the minimum amount of demands of each destination, the extra supplies left are distributed following some utility values illustrated in Table 8. A destination with a high utility value for a class of commodity during a given time slot will be allowed a higher priority, hence is more likely to receive an extra amount of supplies over a destination with a low utility. The utility values in Table 8 are elaborated based on a hypothetical model that allocates different priorities to different destinations for different classes of commodities during different time slots. The values in $[1,6]$ are generated based on the vulnerability of the afflicted areas and populations. A matching function can also be developed between the priorities associated with the demands of the populations and any other interval of utilities. In our model, to have uniform terms in the optimization objective, we set the value of each utility parameter $U_{n,k}^{t}$ of delivering a commodity of class K to destination n during time slot t, in the pricing objective function (10), as the product of the *cost of transporting a pallet* times the associated value in Table 8 .

Table 7: *Demand versus Offer*

Class-of-Commodities	demand (min, max)	offer
K_1	246, 400	320
K_2	240, 400	320
K_3	242, 400	320
Total	728, 1200	**960**

Table 8: *Delivery time utility*

Dstination	Class K	Time-slots					
		1	2	3	4	5	6
1	K_1	5	4	3	2	1	3
	K_2	5	1	2	3	4	5
	K_3	1	5	4	5	3	2
2	K_1	2	5	1	4	3	2
	K_2	2	3	4	5	2	3
	K_3	5	2	2	3	5	4
3	K_1	1	2	3	4	5	6
	K_2	5	4	3	2	1	6
	K_3	1	2	3	4	6	5
4	K_1	1	2	3	4	5	6
	K_2	5	4	3	2	1	6
	K_3	1	2	3	4	6	5
5	K_1	1	2	3	4	5	6
	K_2	5	4	3	2	1	6
	K_3	1	2	3	4	6	5
6	K_1	1	2	3	4	5	6
	K_2	5	4	3	2	1	6
	K_3	1	2	3	4	6	5
7	K_1	1	2	3	4	5	6
	K_2	5	4	3	2	1	6
	K_3	1	2	3	4	6	5
8	K_1	1	2	3	4	5	6
	K_2	5	4	3	2	1	6
	K_3	1	2	3	4	6	5

5.2.3 Scheduling of operations

In this set of experiments, we consider a fleet mix and size of vehicles as presented in the second column of Table 9. In the the third column are presented the number of used assets of each class.

Table 9: *Fleet mix and size*

Asset	Available	Used
MLVW-Cargo	50	5
HLVW-Cargo	50	50
CH-147D Chinook	40	34
CH-146 Griffon	40	0

Table 10 shows the optimal scheduling of the reliefs according to the demands/offers formulated in Tables 6 and 7, and the utility distribution in Table 8. The capital and operating costs of this solution are $\$896,474$ and $2 \times \$90,000$ (cost of building/renting Depots 2 and 3).

Table 10: *Delivered commodities over the schedule time*

Dstination	Class K	Time-slots						Total
		1	2	3	4	5	6	
1	K_1	8	8	8	6	5	5	**40**
	K_2	10	5	5	5	5	10	**40**
	K_3	5	8	6	10	6	5	**40**
2	K_1	3	15	6	6	5	5	**40**
	K_2	5	10	5	7	8	5	**40**
	K_3	6	5	5	5	10	9	**40**
3	K_1	5	5	5	7	8	10	**40**
	K_2	10	5	5	5	5	10	**40**
	K_3	5	5	5	5	10	10	**40**
4	K_1	3	8	10	8	6	5	**40**
	K_2	5	10	5	5	5	10	**40**
	K_3	5	5	5	5	10	10	**40**
5	K_1	5	5	5	7	8	10	**40**
	K_2	10	5	5	5	5	10	**40**
	K_3	5	5	5	5	10	10	**40**
6	K_1	3	8	10	8	6	5	**40**
	K_2	5	10	5	5	5	10	**40**
	K_3	5	5	5	5	10	10	**40**
7	K_1	5	5	5	7	8	10	**40**
	K_2	10	5	5	5	5	10	**40**
	K_3	5	5	5	5	10	10	**40**
8	K_1	3	8	10	8	6	5	**40**
	K_2	5	10	5	5	5	10	**40**
	K_3	5	5	5	5	10	10	**40**
Total		136	165	140	144	171	204	**960**

6 Conclusion

We presented in this report some military logistics dimension of HROs. We first described the context and roles of the military implications in HROs including typical environment characteristics, tasks and interactions with other organizations as well as logistics problems and planning factors involved in HR logistics. Then, new mathematical models for scheduling HR distribution in a disaster relief operation over a multi-period horizon have been proposed. We focused on planning and scheduling distribution of multiple classes of supplies to demand points in a disaster area using two modes of transportation including air and land.

Future work will take on new challenges, increasingly paying attention to end-to-end global supply chain management, coordination and agility issues in distributed and risky environment settings over different types of disasters and scales. As a coalition of relief effort providers, net-centric agile military organizations need to develop and maintain a shared persistent situational awareness and rapid response capability to meet emerging and future HROs complexity.

References

[1] Centre for Research on Epidemiological Disasters (Accessed November 2012), http://www.cred.be.

[2] Tomasini, R.M. and Wassenhove, L.N. Van (2009), From preparedness to partnerships: case study research on humanitarian logistics, *Intl. Trans. in Operations. Reseach*, 16(5), 549–559.

[3] Inter-Agency Standing Committee (Accessed November 2012), http://www.humanitarianinfo.org/iasc.

[4] Thomas, A.S. and Kopczak, L.R. (2005), From logistics to supply chain management: the path forward in the humanitarian sector, *Fritz Institute*, Vol. 15.

[5] Chief of Force Development (2009), The Future Security Environment 2008-2030. Part 1: Current and emerging Trends., National Defence of Canada.

[6] Chief of Force Development (2009), Integrated Capstone Concept, National Defence of Canada.

[7] DFAIT (2012), Last accessed: Feb 2012. `http://www.international.gc.ca`.

[8] DND, CEFCOM (2012), Last accessed: Feb 2012. `http://www.comfec-cefcom.forces.gc.ca`.

[9] Sebbah, S., Ghanmi, A., and Boukhtouta, A. (2011), Design of Tactical Support Strategies in Military Logistics: Trade-offs Between Efficiency and Effectiveness, Technical Report DRDC CORA, TR 2011-211.

[10] Chang, M.S., Tseng, Y.L., and Chen, J.W. (2007), A scenario planning approach for the flood emergency logistics preparation problem under uncertainty, *Transportation Research Part E: Logistics and Transportation Review*, 43(6), 737–754.

[11] Tzeng, G.H., Cheng, H.J., and Huang, T.D. (2007), Multi-objective optimal planning for designing relief delivery systems, *Transportation Research Part E: Logistics and Transportation Review*, 43(6), 673–686.

[12] Balcik, B., Beamon, B., and Smilowitz, K. (2008), Last mile distribution in humanitarian relief, *Journal of Intelligent Transportation Systems*, 12(2), 51–63.

[13] Thomas, A. (2008), Humanitarian logistics: enabling disaster response, Fritz Institute.

[14] Center for excellence in disaster management & humanitarian assistance, http://www.coe-dmha.org/media/guidance/3MCDAGuidlines.pdf, Guidelines on the use of military and civil defence assets to support united nations humanitarian activities in complex emergencies.

[15] Mason, D.W. and Dickson, P.D. (2007), Analysis of Risks Associated With Reliance on Non-Integral Strategic Airlift Solutions, Technical Report DRDC CORA 2007-17.

[16] Altay, N. and Green, W.G. (2006), OR/MS research in disaster operations management, *European Journal of Operational Research*, 175(1), 475–493.

[17] Kovács, G. and Spens, K. (2009), Identifying challenges in humanitarian logistics, *International Journal of Physical Distribution & Logistics Management*, 39(6), 506–528.

[18] Balcik, B., Beamon, B.M., Krejci, C.C., Muramatsu, K.M., and Ramirez, M. (2010), Coordination in humanitarian relief chains: Practices, challenges and opportunities, *International Journal of Production Economics*, 126(1), 22–34.

[19] Thomas, A. and Kopczak, L.R. (2007), Life-saving supply chains, *Building Supply Chain Excellence in Emerging Economies*, pp. 93–111.

[20] Van Wassenhove, L.N. (2005), Humanitarian aid logistics: supply chain management in high gear, *Journal of the Operational Research Society*, 57(5), 475–489.

[21] Oloruntoba, R. (2005), A wave of destruction and the waves of relief: issues, challenges and strategies, *Disaster Prevention and Management*, 14(4), 506–521.

[22] Cruijssen, F., Cools, M., and Dullaert, W. (2007), Horizontal cooperation in logistics: opportunities and impediments, *Transportation Research Part E: Logistics and Transportation Review*, 43(2), 129–142.

[23] Thomas, A. (2004), Leveraging private expertise for humanitarian supply chains, *Forced Migration Review*, 21, 64–65.

[24] Sebbah, S., Ghanmi, A., and Boukhtouta, A. (2011), Modeling and simulation of military tactical logistics distribution, In *Winter Simulation Conference*, pp. 1–11.

[25] Tovia, F. (2007), An emergency logistics response system for natural disasters, *International Journal of Logistics Research and Applications*, 10(3), 173–186.

[26] Institute, Fritz (Accessed November 2012), http://www.fritzinstitute.org.

[27] Ghanmi, A., Martel, A., Berger, J., and Boukhtouta, A. (2009), A Methodology for the Design and Management of Canadian Operational Supply Network, In *proceedings of IEEE Symposium on Computational Intelligence for Security and Defense Applications*, pp. 1340–1348.

[28] Beresford, A.K.C. and Rugamba, A. (1996), Evaluation of the transport sector in Rwanda, *UNCTAD, Geneva*.

[29] Simpson, N.C. and Hancock, P.G. (2009), Fifty years of operational research and emergency response, *Journal of the Operational Research Society*, 60, 126–139.

[30] Pettit, S.J. and Beresford, A.K.C. (2005), Emergency relief logistics: an evaluation of military, non-military and composite response models, *International Journal of Logistics Research and Applications*, 8(4), 313–331.

[31] Iori, M., González, J.J.S., and Vigo, D. (2007), An exact approach for the vehicle routing problem with two-dimensional loading constraints, *Transportation Science*, 41(2), 253–264.

[32] Laporte, G. (1992), The vehicle routing problem: An overview of exact and approximate algorithms, *European Journal of Operational Research*, 59(3), 345–358.

[33] Toth, P. and Vigo, D. (2002), The vehicle routing problem, Society for Industrial Mathematics.

[34] Campbell, A.M., Vandenbussche, D., and Hermann, W. (2008), Routing for relief efforts, *Transportation Science*, 42(2), 127–145.

[35] Nolz, P., Doerner, K., Gutjahr, W., and Hartl, R. (2010), A bi-objective metaheuristic for disaster relief operation planning, *Advances in Multi-Objective Nature Inspired Computing*, pp. 167–187.

[36] Huang, M., Smilowitz, K., and Balcik, B. (2011), Models for relief routing: Equity, efficiency and efficacy, *Transportation Research Part E: Logistics and Transportation Review*.

[37] Mete, H.O. and Zabinsky, Z.B. (2010), Stochastic optimization of medical supply location and distribution in disaster management, *International Journal of Production Economics*, 126(1), 76–84.

[38] Knott, R. (1987), The logistics of bulk relief supplies, *Disasters*, 11(2), 113–115.

[39] Barbarosoglu, G., Ozdamar, L., and Cevik, A. (2002), An interactive approach for hierarchical analysis of helicopter logistics in disaster relief operations, *European Journal of Operational Research*, 140(1), 118–133.

[40] Özdamar, L., Ekinci, E., and Küçükyazici, B. (2004), Emergency logistics planning in natural disasters, *Annals of Operations Research*, 129(1), 217–245.

[41] Van Hentenryck, P., Bent, R., and Coffrin, C. (2010), Strategic planning for disaster recovery with stochastic last mile distribution, *Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems*, pp. 318–333.

[42] Salmerón, J. and Apte, A. (2010), Stochastic optimization for natural disaster asset prepositioning, *Production and Operations Management*.

[43] Rawls, C.G. and Turnquist, M.A. (2010), Pre-positioning of emergency supplies for disaster response, *Transportation Research Part B: Methodological*, 44(4), 521–534.

[44] Shen, Z., Dessouky, M.M., and Ordóñez, F. (2009), A two-stage vehicle routing model for large-scale bioterrorism emergencies, *Networks*, 54(4), 255–269.

[45] Haghani, A. and Oh, S.C. (1996), Formulation and solution of a multi-commodity, multi-modal network flow model for disaster relief operations, *Transportation Research Part A: Policy and Practice*, 30(3), 231–250.

[46] Yi, W. and Ozdamar, L. (2007), A dynamic logistics coordination model for evacuation and support in disaster response activities, *European Journal of Operational Research*, 179(3), 1177–1193.

[47] Desrochers, M., Desrosiers, J., and Solomon, M. (1992), A new optimization algorithm for the vehicle routing problem with time windows, *Operations Research*, 40(2), 342–354.

[48] Fisher, M. (1995), Vehicle routing, *Handbooks in operations research and management science*, 8, 1–33.

[49] Jimenez, F. and Verdegay, J.L. (1999), Solving fuzzy solid transportation problems by an evolutionary algorithm based parametric approach, *European Journal of Operational Research*, 117(3), 485–510.

[50] Ziliaskopoulos, A. and Wardell, W. (2000), An intermodal optimum path algorithm for multimodal networks with dynamic arc travel times and switching delays, *European Journal of Operational Research*, 125(3), 486–502.

[51] Ribeiro, C. and Soumis, F. (1994), A Column Generation Approach to the Multi-Depot Vehicle Scheduling Problem, *Operations Research*, 42, 41–52.

[52] Kaluzny, B.L. and Erkelens, A.J. (2008), The Optimal MSVS Fleet for First-Line Replenishment, Technical Report Materiel Group Operational Research, DRDC CORA, TR 2006-026.

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1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence R&D Canada – CORA Dept. of National Defence, MGen G.R. Pearkes Bldg., 101 Colonel By Drive, Ottawa, Ontario, Canada K1A 0K2	2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED (NON-CONTROLLED GOODS) DMC: A REVIEW: GCEC June 2010

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Humanitarian Relief Operations: A Military Logistics Perspective

4. AUTHORS (Last name, followed by initials – ranks, titles, etc. not to be used.)

Sebbah, S.; Boukhtouta, A.; Ghanmi, A.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information. Include Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
November 2012	62	52

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Memorandum

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Defence R&D Canada – CORA
Dept. of National Defence, MGen G.R. Pearkes Bldg., 101 Colonel By Drive, Ottawa, Ontario, Canada K1A 0K2

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10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
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Humanitarian logistics is defined as the process of planning, implementing and controlling the efficient, cost effective flow and storage of goods and materials as well as related information from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing. However, several factors may obstruct the flows of reliefs and information in humanitarian relief operations (HROs) and negatively affect the effectiveness of the involved organizations. Problems such as scarcity of reliefs and logistics means to efficiently distribute the goods, location/allocation of distribution centres and storage capacity, flow bottlenecks in the humanitarian relief network, security of convoys, fairness in reliefs distribution, etc. may appear at different stages of the HROs and prevent the reliefs from reaching the needy populations.

This study considers HROs from a military tactical logistics perspective. We review some challenging problems in HROs. We then propose mathematical planning and optimization models to address some of these problems. Finally, we give some concluding remarks and some future research venues.

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Humanitarian relief operations, military logistics