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A column-and-cut generation algorithm for planning of Canadian armed forces tactical logistics distribution

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ABSTRACT

The military tactical logistics planning problem addresses the issue of distributing heterogeneous commodities (e.g., food, medical supplies, construction material, ammunition, etc.) to forward operating bases in a theatre of operations using a combination of heterogeneous transportation assets such as logistics trucks and tactical helicopters. Minimizing the logistics operating cost while satisfying the operational demands under time and security constraints is of high importance for the Canadian Armed Forces. In this study, a logistics planning model is developed to explore the trade-offs between the *effectiveness* and *efficiency* in military tactical logistics distribution. A mathematical optimization algorithm based on Column-and-Cut generation techniques is developed to find the fleet mix and size of transportation assets to meet different Quality-of-Support (QoS) parameters.

This paper presents details of a new column generation decomposition approach and a solution algorithm along with an application example to demonstrate the methodology. Extensive computational results are presented in order to measure the degree of efficiency and scalability of the proposed approach, and to analyze the trade-offs between: (1) delivery time and operating cost; (2) security and operating cost.

1. Introduction

1.1. Preliminaries

The Canadian military logistics system is a large-scale and complex network that involves many inter-related processes, decisions, and military bodies. The tactical part of the system involves operations in the field ranging from building of logistics networks to developing transportation strategies to supply deployed troops. A crucial component of the military tactical logistics is the transportation and distribution of supplies in the field. The Canadian Armed Forces (CAF) uses a variety of transportation modes including air/land/sea to distribute heterogeneous commodities (e.g., fuel, food, ammunition, etc.) in the field of operations.

Given the amount of supplies the CAF transports during each mission and the incurred cost, optimization of the logistics operating costs is becoming crucial to the effective and efficient support of the CAF. In the design of military logistics distribution strategies, as well as commercial logistics strategies, there are different trade-offs between the capital/operating costs and the achievable support performances [1–3]. Focusing solely on the logistics costs may result in strategies that are less flexible and not effective in meeting the requirements of deployed troops. For example, using the land transportation mode, e.g., trucks, to reduce transportation costs may increase the delivery time and the vulnerability of the transported supplies. Furthermore, a flexible supply strategy is the one that can be dynamically changed to respond to a new unexpected event with less disturbance of the whole logistics chain. Such a supply strategy is usually not necessarily highly optimized [4–7].

In the military, the trade-off between efficiency and effectiveness appears at different levels during the deployment[1] and sustainment[2] phases. During the deployment phase, the operational support goals are to ensure deployment speed by reducing the time, as much as possible, while keeping its cost at its lowest value. Similarly, during the sustainment phase, the objective is to ensure that the deployed forces are able to achieve their objectives while minimizing the cost to provide the required support level. The CAF logistics planners are continually called to elaborate strategies and take decisions at different levels to balance between these two dual concepts. In tactical logistics, given the increasing cost of operations and the sensitivity of some missions, the trade-off between the efficiency and effectiveness of operations needs extensive analysis to find good balances for different logistics scenarios.

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[1] Period during which troops move into position for military action.
[2] Period during which troops are in the field of operations.

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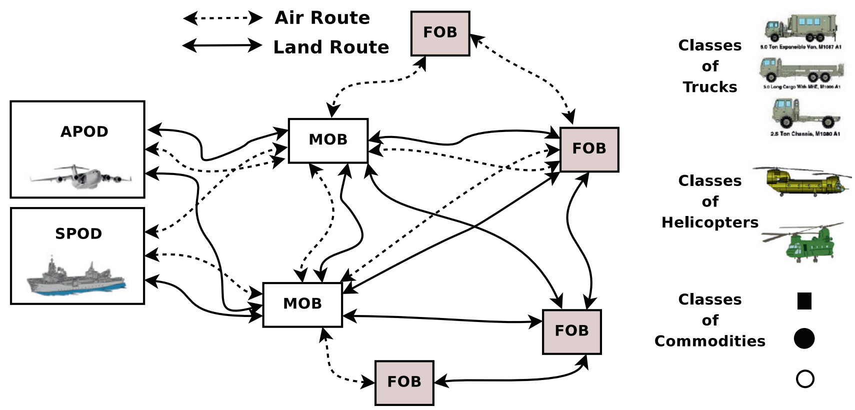

Fig. 1. Tactical logistics schematic theatre lay-out.

In this paper, we focus on the design problem of tactical logistics distribution strategies that achieve different balances between the support efficiency and its effectiveness. While efficiency measures how economic is the logistics strategy, we define the following metrics to measure the effectiveness of a tactical logistics distribution strategy: delivery time, loading and transportation safety, and security of transportation assets and commodities. We refer to these metrics as Quality-of-Support (QoS). Our contributions in this paper include: (i) an Integer-Linear Program (ILP) formulation to find the loading and routing of an optimized fleet mix and size of assets that minimize the operation cost, subject to constraints including: payload and bulk transportation capacities; transportation safety of commodities, suitability of the transportation assets to transport commodities of some classes, and priorities of the demands (delivery time). (ii) Following the Column Generation (CG) approach, we decompose our problem of building global logistics distribution strategies into building smaller loading and routing plans, referred in this paper by *support plans*. (iii) We analyze the integrality gap of the CG algorithm, and develop a strengthening cutting plane algorithm based on the Gomory–Chvátal cutting plane approach.

This paper is organized as follows. Section 2 gives an overview of our military tactical logistics network model. Section 3 reviews some existing work on logistics distribution. Section 4 provides mathematical optimization models and solution algorithms for our logistics distribution strategies design problem. Section 5 presents experimental results on the trade-off between efficiency and effectiveness. Section 6 concludes the paper.

2. Canadian military tactical logistics distribution system

2.1. *Tactical logistics network topology*

Fig. 1 illustrates a small example of a Canadian military tactical logistics distribution network. It is composed of a set of nodes including Air/Sea Port of Disembarkation ((A/S)PODs), Main Operating Bases (MOB),[3] Forward Operating Bases (FOBs),[4] interconnected by bidirectional links representing the routes. Plain and dash links are used to distinguish between the disjoint air and land routes in the network. Each link is characterized by its distance and some other metrics we will detail later on. The design problem of a tactical logistics distribution network is a strategic decision one that is greatly influenced by diplomatic relations with the neighbour countries in the vicinity of the deployment field and international laws. The location of nodes, the design of air and land routes are directly dictated by the available resources. For our tactical logistics distribution problem, that the network topology is given as it is a strategic problem.

2.2. *Transportation model*

In terms of material flows, supplies received at the (A/S)PODs are delivered to FOBs through MOBs using tactical trucks and helicopters. Nearly all supplies moved from one location to another are loaded on standard cargo pallets. Commodities with a common destination and origin can be aggregated into a similar pallet. Contrary to the size of the pallets which is similar, the weight of a pallet is defined by the type of commodity it contains. In this model, we adopt the following loading and routing rules:

- Demands for commodities are expressed in terms of number of pallets and a pallet contains commodities of a single class of commodities.
- Multiple visits to a destination are required during different time intervals to deliver all the required commodities.
- Transportation assets of different classes and modes are prepositioned at different nodes to transport commodities from their current locations to the next nodes or to their destinations.
- A transportation asset departing from a location returns back to the same location after delivering its load.
- The mode of transportation and/or class of transportation assets may be changed at intermediate nodes during transportation of commodities from a source to a destination. For example, a Chinook helicopter would be used to from the APOD to a MOB, then, Light Support Vehicle Wheeled (LSVW) trucks to distribute the commodities to their FOBs.
- All nodes are equipped with the necessary transhipment capabilities, however, the required time to do it is not the same everywhere.

In addition to these rules, some others related to the safety and security of commodities and transportation assets are used in this military tactical logistics model. First, some classes of commodities are never clustered together on the same lift from one location to another. For example, pallets of ammunition and food are never clustered together. Second, depending on the sensitivity of a class of commodities, some classes of transportation assets (e.g., more reliable) may be preferred over others, e.g., air mode may be used to transport sensitive military material in conflict areas. Third, depending on the nature of a route (e.g., sandy or stoney) and its capacity, some classes of transportation assets may be allowed and others not. By capacity, we mean the load capacity of a bridge, if any, along the route. These rules are used to ensure safe loading of

[3] Major facilities, permanently manned, support permanently deployed forces.
[4] Smaller facilities, temporarily manned, serve as contingency tactical locations.