Task 1: Two-echelon supply network management – Problem characterization

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Task 1: Two-Echelon Supply Network Management -

Problem Characterization

April 16, 2013

DRDC Valcartier DRDC

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CHANGE RECORD

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ACRONYMS AND ABBREVIATIONS

3PL	Third-Party Logistics provider
AHSVS	Armoured Heavy Support Vehicle System
AOO	Area of Operations
APOD	A Port of Disembarkation
BC	British Columbia
CANOSCOM	CANadian Operational Support COMmand
CF	Canadian Forces
CFJOSG	Canadian Forces Joint Operational Support Group
DA	Future Decision Support System for Operational and Tactical Logistics
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DTAV	Defence Total Asset Visibility
FOB	Forward Operating Base
GUI	Graphical User Interface
HFD	Highly-Fluctuating-Demand-Items
HLVW	Heavy Logistic Vehicle Wheeled
JTF	Joint Task Force
LAV	Light Armoured Vehicle
LTL	Less-than a Truck-Load
MBC	Main Delivery Base in Canada
MDA	MDA Systems Ltd.
NSE	National Support Element
POL	Petroleum, Oil, and Lubricants
PLS	Palletized Loading System
RFID	Radio Frequency Identification
SCM	Supply Chain Management
SCN	Supply Chain Network

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SOW	Statement of Work
TA	Technical Authority
TAV	Technical Assistance Visits
US	United States
WPEQ	Water Pallet Equivalent
WWI	World War I
WWII	World War II

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1 INTRODUCTION

This document represents the Task I Interim Report for project "In-theatre 2-echelon supply chain management – preliminary models and algorithms". The work has been executed by MDA Systems Ltd. (MDA) under the Defence Research and Development Canada (DRDC) Contract No W7701-125337/001/QCL.

The focus of the project is on preliminary models and algorithms for decision support of the transportation and inventory activities related to the tactical and possibly operational logistics. The aim is to support decision makers and analysts of the Canadian Operational and Tactical Support Commands.

The objective of the project is to research new problems, concepts, models, and algorithms addressing issues such as hostile or chaotic environments, and stochastic events and demands.

The Statements of Work (SOW) for the project divide the work in two tasks. The task deliverables include one or more Interim Reports. The deliverable of Task 1 is one Interim Report. This document represents the Task 1 deliverable.

The scope of this document is defined by the title of Task 1: Two-echelon supply network management – problem characterization.

The layout of this report is:

- Section 2 provides some background material
- Section 3 describes the structure of the supply chain network
- Section 4 introduces the problems and their characterizations
- Section 5 gives examples of values of certain problem characteristics describing the current situation in Canada and CF

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2 BACKGROUND: GAPS AND REQUIREMENTS

This section provides background material taken from the final report of previous project "Issues and Challenges Related to the Tactical and Operational Logistics" [MC_2011].

Proposed enhancements to the Canadian tactical in-theatre supply chain management included [MC_2011, Section 4.2.3]:

1. Merging Operational and Tactical supply chains.
2. New technologies should be considered for implementation:
   a) Faster collection of requests (via radio),
   b) Better forecasting (including consideration of future mission plans),
   c) Improved inventory management (incorporating automated systems),
   d) Transportation (improved planning, routing and scheduling).
3. Transportation services for materiel and personnel have to be considered together.

From these proposed enhancements, this project will address inventory management and transportation strategies. Also, there is a possibility that the project will partially address the forecasting issues and merging of the entire DND Supply Chain Network.

2.1 Relevant Tactical Logistics IT Gaps

From the gaps identified in Section 6 of [MC_2011] report, this project will address gaps from Operations Management (G4 group) shown in Table 2-1:

G4.1 Distribution management gaps:

- G4.1.1 Distribution planning, including entire supply chain
- G4.1.2 Computer support for routing and scheduling in order to fulfill transportation requests or to resolve trade-offs between time, costs, and risks; heterogeneous fleet, heterogeneous loads; pre-configured loads
- G4.1.3 Real-time distribution planning
- G4.1.4 Dynamic routing with re-routing capabilities in order to react to unexpected demands
- G4.1.5 Replenishment cycle changes

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G4.2 Inventory management gaps:

G4.2.5 Re-supply, i.e., replenishment

Table 2-1 Tactical Logistics IT Gaps to be considered in this project [MC_2011, Section 6.3]

Gap category	Gap	Description	Research in progress	Implementation in progress	Fielding in progress	Currently operational	Achieved	Priority/ importance	Potential technology for enhancement
G4. Operations Mgmt.	G4.1	Distribution management	✓	✗	✗	✗	●	▬ (2/4)	Optimization tools
	G4.2	Inventory management	✓	✗	✗	✗	●	▬ (2/4)	Optimization tools

2.2 Relevant Requirements

The general requirements are taken from [MC_2011, Section 7.2]. "DA" is term used within this document for the proposed future Decision Support system for Operational and Tactical Logistics.

These general requirements are listed here as a source of information that might be used for solving inventory management and distribution management problems. The specific requirements or portions of the requirements that are to be addressed in the project are underlined.

2.2.1 Relevant SCM Requirements

This list presents functional requirements for the DA related to operations management of the logistics activities. These requirements would support more efficient operations and thus focused logistics. They would also support rapid distribution and agility.

Requirement	Description	Gaps
Distribution management		
DA-REQ-600	The DA should have tools/algorithms that provide lists of transportation requests based on forecasts, demand, and min/max stock levels at each node of the distribution network. Real-time/ dynamic aspects of the problem have to be supported. Changes to replenishment cycle have to be supported.	G4.1.1, G4.1.3, G4.1.5
DA-REQ-603	The DA should have tools/algorithms for dynamic routing and scheduling of the heterogeneous fleet of vehicles to satisfy requests for transportation of people and materiel. Optimization and multi-criteria decision making should be included. The tools have to provide multiple solutions/ alternatives among which a decision maker will choose. Re-routing, transshipment, pre-configured loads should be supported.	G4.1.2, G4.1.3, G4.1.4
Inventory management		

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Requirement	Description	Gaps
New	The DA should have inventory management tools for finding and managing the stock levels at all warehouse locations.	G4.2.4

2.2.2 Relevant UI Requirements

This list presents relevant user interface requirements for the DA.

Requirement	Description	Gaps
DA-REQ-104	The DA should provide decision support GUI that allow user/ decision maker to use (select or change) solutions provided by the tools and algorithms listed in Section 2.2.1. The tools are supposed to provide multiple solutions/ alternatives, with different metrics, so that the decision makers can easily understand trade-offs and choose appropriate alternatives quickly.	G4: Very limited interface

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3 TWO-ECHELON SUPPLY CHAIN MANAGEMENT

3.1 Introduction

The introduction, motivation, and main definitions relevant to this project may be found in [MC_2011] where both tactical and operational logistics for DND operations are discussed.

We consider the DND military and humanitarian operations. Humanitarian operations include disaster relief operations in Canada or abroad. The similarities and differences between these operations in terms of transportation and inventory problems are laid down in Section 3.3 and Section 5.

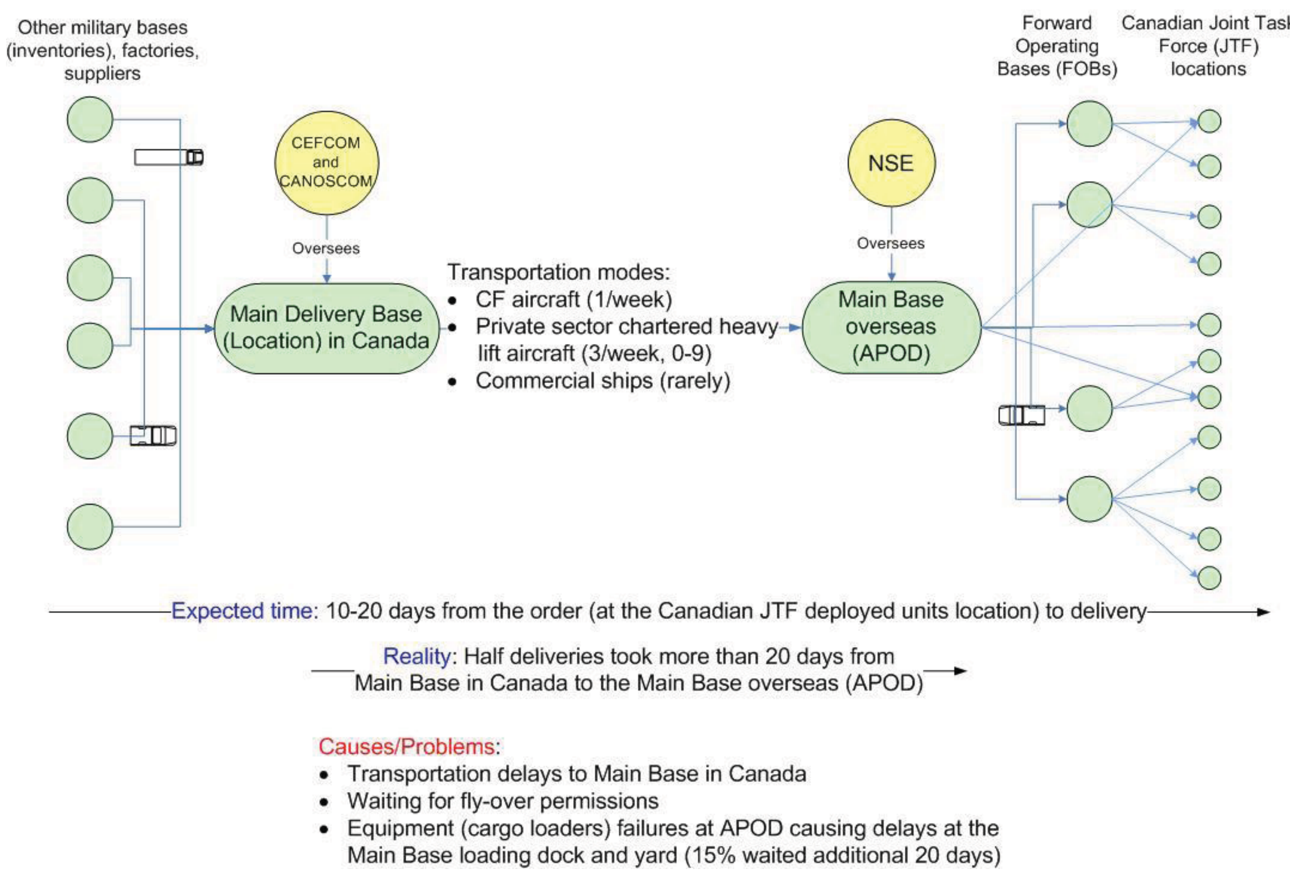

Figure 3-1 Materiel Distribution Network with Performance Analysis [MC_2011]

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3.2 Supply Chain Network (SCN)

The DND Supply Chain Network (Figure 3-1) consists of the:

- Operational SCN – the portion of the SCN from the locations in Canada to the APOD, and
- Tactical SCN – the portion of the SCN from the APOD to the forward operating DND units.

The Operational SCN was managed by Canadian Forces Joint Operational Support Group (CFJOSG) since October 2012, earlier known as CANOSCOM.

The Tactical SCN is managed by NSE. More precisely, only transportation activities from APOD to FOBs are managed by NSE, while the transportation activities beyond FOBs are under jurisdiction of operational units as shown in Figure 3-2.

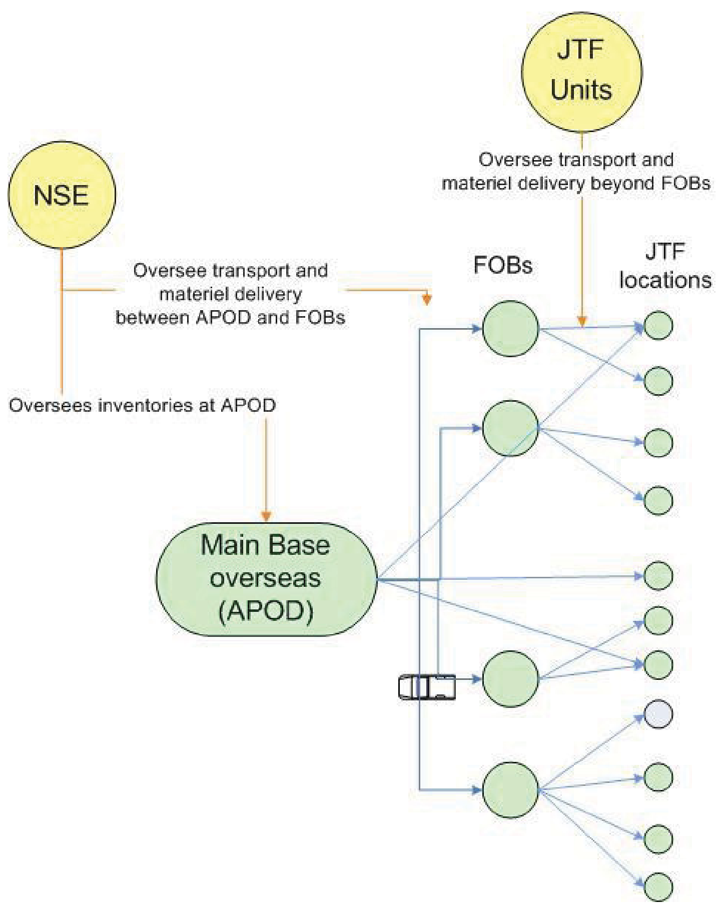

Figure 3-2 Tactical Supply Chain Network: Management Jurisdictions in Military Operations

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This characteristic of the problem is to be kept in mind for the future research when the distributed version of the supply chain management is to be considered.

For now, we will assume that the supply chain management is a centralized problem.

3.3 Entire SCN vs. Tactical SCN

For the CF operations, the path of supplies through the SCN is determined by their location of origin. Thus, the situation is as follows:

- The tactical SCN is sufficient to consider for the locally purchased supplies:
  - Food (80% local, 20% Canada)
  - Water (90% local)
  - Petroleum, Oil, and Lubricants (POLs) (100% local)
- The entire SCN has to be considered for the supplies coming from Canada or from a far-away supply location:
  - Medical supplies (100% Canada)
  - Equipment (100% Canada)
  - Spare parts (100% Canada)
  - Other military operations consumable materiel (100% Canada)

Locally purchased supplies sometimes come through the APOD, and sometimes are delivered directly to FOBs. For example, around 90% of the locally purchased water is bottled water, and it is delivered to the APOD first before it is transported to FOBs by the NSE vehicles.

In disaster relief operations, the situation is similar when dealing with international relief operations for the disasters abroad, or when dealing with potential mega-disasters in Canada. For example, in the case of a mega-earthquake that may happen in Western Canada, all of Canada may be involved in the relief operation, and the origins of some supplies might be far-away. Thus, the portions of the SCN that needs to be considered would be as follows:

- The tactical SCN is sufficient to consider for the locally purchased supplies:
  - Food (80% local or from close by locations)
  - Water (90% local or from close by locations)
- The entire SCN has to be considered for the supplies coming from Canada-at-large or from a far-away supply location:
  - Medical supplies (100% from further locations in Canada)
  - Equipment (100% from further locations in Canada)

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In the literature, the term echelon refers to the number of levels of the network that has vehicle fleets used for distributing supplies the next level forward. Thus, Figure 3-1 shows a four-echelon SCN, and Figure 3-2 shows a two-echelon SCN.

To conclude, due to:

- The origins of the supplies
- The complexity of the problem
- The large differences between the SCM issues in the operational and tactical SCNs
- Earlier challenges arising from the operational/tactical SCN division

This project will consider the centralized management of the extended two-echelon SCN shown in Figure 3-3. If the sub-problems dealing only with the supplies originating at the close supply node are to be considered, we will have the two-echelon SCM problem.

The newly proposed SCN division – to the extended two-echelon SCN and the operational SCN – with the repeated Canada-APOD edge would provide opportunities to manage the entire network more efficiently.

The modes of transportation within our extended two-echelon SCN are as follows:

- o The first level of the SCN: Between the far supply node (Canada) and the close supply node (APOD): aircrafts, private sector chartered heavy lift aircraft, commercial ships. This is the Fleet F0 in Figure 3-3.
- o The second and third levels of the SCN: trucks, armoured vehicles, aircrafts; often in convoys. These are the Fleet F1 and F2 in Figure 3-3.

3.3.1 The Extended Two-Echelon SCN

The Extended Two-Echelon SCN should be considered for:

- Military operations: for the supplies coming from Canada
- Disaster relief operations:
  - o Disaster relief abroad
  - o Domestic mega-disaster: for the supplies coming from far-away locations in Canada.

The decision support for the inventory and distribution management is assumed to be centralized.

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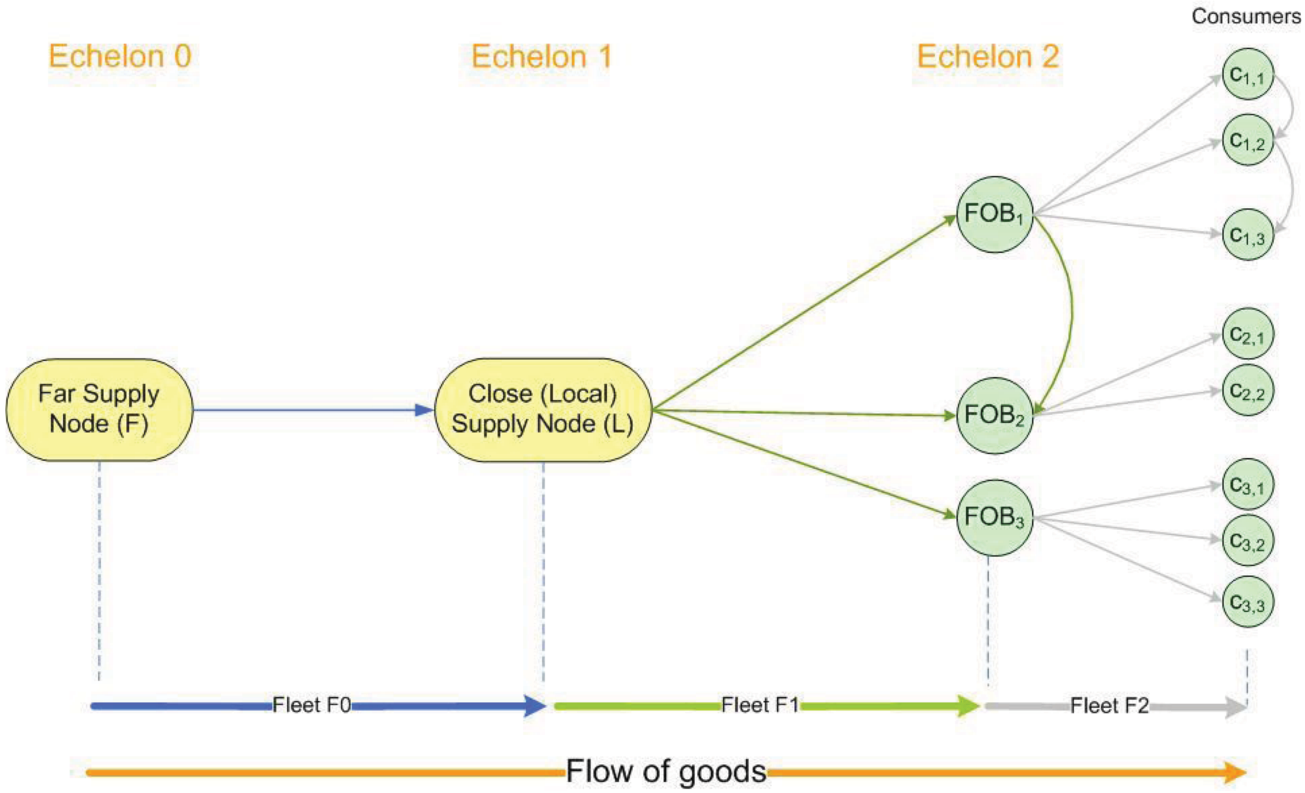

Figure 3-3 The extended two-echelon Supply Chain Network

Considering the extended two-echelon SCN provides additional advantages:

- It would address reasons for the past distribution delays as shown in Figure 3-1.
- The supply of goods originating from Canada (spare parts, medical supplies, and the military operation consumable materiel) would be modeled properly.
- It would address the main recommendations from the initial Tactical Logistics project: to consider the entire DND supply chain network.

3.3.2 The Two-Echelon SCN

The two-echelon SCN would be enough to consider when dealing with:

- Military operations: for the supplies purchased locally (water, food, and POLs)
- Relief operations for domestic disasters that can be dealt with within one province

The decision support for the inventory and distribution management is assumed to be centralized. All the supplies purchased locally are delivered to APOD and then transported to FOBs by the NSE vehicles.

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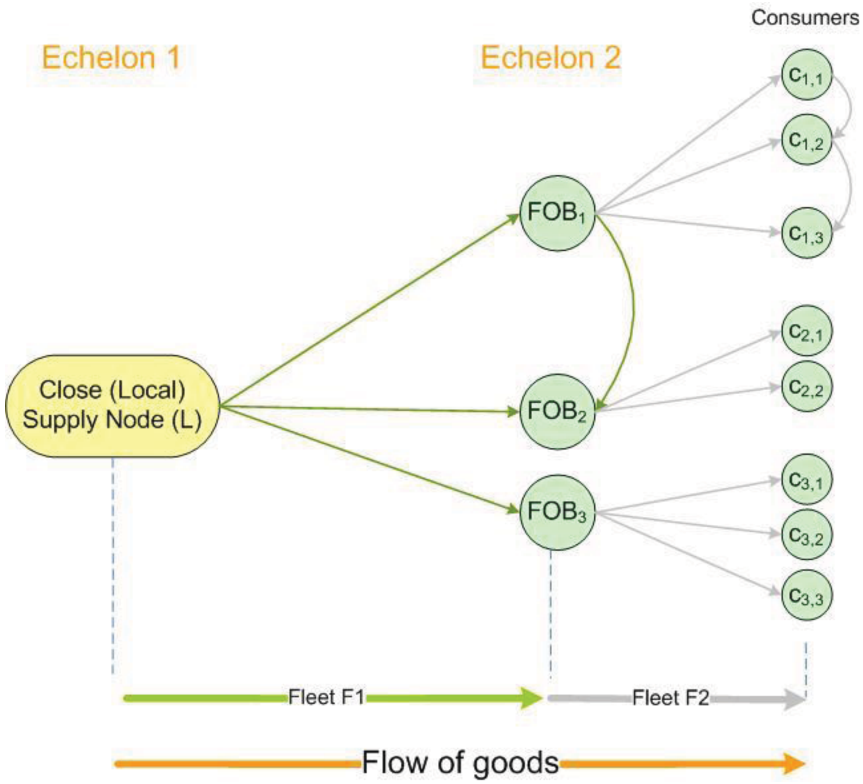

Figure 3-4 The two-echelon SCN – the tactical SCN

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4 PROBLEM DEFINITION AND CHARACTERIZATION

The characteristics of the supply chain management problem that are novel compared to the state-of-the-art literature include:

- Inventories at each node of the SCN
- Transportation times in the first level of the SCN are measured in weeks, while the travel times in the last level of the SCN are measured in hours or minutes
- High standard deviation for the transportation times in the first level of SCN (where the travel times are the longest)
- Two different types of products:
  - One with highly uncertain demand
  - The other with relatively stable demand
- Risks and safety issues are present at the latest level of the SCN: security risks (adversaries) or the transportation network unavailability
- Potential presence of intelligent opponents that is increasing the risks further within the last level of the SCN

We plan to conduct rigorous modeling of the problem and potentially mathematical programming formulation of the merged inventory management and distribution problems which will also be novel.

Out of the supplies we will consider in this project, the demand for some supplies is much less predictable than the others. We identified two such categories of supplies:

- Medical supplies in chaotic environments during disaster relief operations
- Military operation consumable materiel in hostile environments

The demand for these supplies fluctuates greatly, and the demand level is rarely known very far in advance. Let us call them Highly-Fluctuating-Demand supplies, or HFDs. In addition, these items are often hard to handle: medical supplies often need refrigerators and special handling; military operation consumable materiel often needs special trucks and is not allowed to be unloaded on the ground (‘keep it on wheels’), etc. Furthermore, in chaotic/ hostile environments there is a high probability that the warehouse and transportation of the above items need to be secured.

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What we learned:

- Demand for food, water, and POLs is much more predictable than demand for medical supplies and certain military consumables (here-named HFDs).
- It seems that the transportation activities in the tactical SCN are very rarely characterized by unavailability of transportation assets: the number of trucks available is usually larger than the number of trucks needed for each particular day of the week. The reasons are the high probability of the truck breakdowns in a hostile, uncertain environments and the high need for the backup trucks that have to be available on short notice. A similar situation might be expected in the disaster relief operations. For example, in natural disasters, the transportation assets would be available after a very short time period and the main shortages would be in the medications supplies.
- Regarding the transportation problem in the tactical SCN, it seems that an additional challenge is to plan unpredictable routes so that the safety of the transportation convoy is not compromised. It will be true in both chaotic and hostile environments. This problem seems to be related to the money collecting truck routing problem, where the trucks also need to follow routes that are not easy to predict.
- Other pressing problems include the identification of appropriate min and max stock levels, and the decisions when to replenish, or when to change the replenishment cycle, under stochastic travel times and stochastic demand, and potential unsuccessful deliveries.
- The vehicle routing problem would be more prevailing in urban than in rural environments.

4.1 Problems

From the three problems listed in this section, we will select one to work on within the Task 2 of this project.

4.1.1 Supply Chain Management Problem and Forecast Tracking

Supply chain management problem for HFD materiel: for a given SCN, given fleet of transportation assets, and given stochastic demand, solve the combined inventory and transportation management problem. This problem consists of the following three components:

1. Inventory management problem:
   - Plan / determine stock levels for a given demand in the consumer nodes (last echelon) and for a given fleet of transportation assets: find the most desirable

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inventory levels (or level ranges: min/max) per article for APOD and each individual FOB.

- Replenishment strategy: moving from pull strategy to push strategy; a hybrid strategy might be considered.
- Determine replenishment cycle and supplies
- (Potentially) Consider warehouse capacities at APOD and FOBs.
- (Potentially) Consider and model losses at FOBs and beyond. Modeling losses at APOD could also be used for modeling the lost items within a large warehouse due to lack of RFIDs.
- Other inventory problems that are either to be considered and modeled explicitly, or somehow taken into account:
  - Scheduling of unloading/ loading equipment
  - Scheduling of packing/re-packing tasks and staff
  - Monitoring and discarding of outdated materiel

2. Transportation management (distribution planning):
   - Multi-commodity network flow problem
3. Forecasting demand and tracking the forecasts.

4.1.2 Vehicle Routing Problem in Tactical SCN

For the supplies with more predictable demand (water, food, POLs), assuming possible transportation route APOD-FOB1-FOB2-FOB3-APOD or any portion of it, for the given demand, given frequency of routes, and given fleet of vehicles, determine the set of routes that satisfy the demand.

Consider the following:

- Vehicle routing and scheduling problem
- Multi-modal transportation
- Transportation control includes DND fleet of vehicles, common carrier, contract carrier, or third-party logistics provider (3PL)
- Assigning of materiel to vehicles (depending whether there are many restrictions and conflicts between goods being transported in the same vehicles)

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- Delivery scheme: direct shipment, cross docking[1], and third-party logistics

4.1.3 Diversification of Truck Routes

In the tactical SCN, plan routes that are more unpredictable for the enemy/ thieves so that the safety of the transportation convoy is not compromised. This problem seems related to the routing problem for money-collecting trucks.

In the scientific literature, a problem of this type is called the *m*-peripatetic salesman problem [Wolfler Calvo et al, 2010] where *m* edge-disjoint tours of minimum total length must be found. In this project, however, the number of possible alternative routes may be limited. So, there is also a need to provide alternative schedules for a given route.

However, a presence of an intelligent adversary may require other more sophisticated means of modeling and solving the problem, including game theoretic approaches, which is out of the scope of this project.

4.2 Problem characterizations

This section provides problem elements and identifies those that potentially have a stochastic nature, *i.e.*, whose values are not deterministic but can be characterized by a certain probability distribution. We will use iterative approach in model development to handle the problem complexity.

4.2.1 Problem elements and characteristics

In this study, we consider centralized decision-making approach to the inventory and transportation problems in the CF logistics. The problem characteristics include:

- Different modes of transportation
- Vehicle fleet
  - Separate vehicle fleets between any two echelons
  - Heterogeneous vehicle fleets
  - Fleet size

[1] **Cross-docking** is a practice in logistics of unloading materiels from an incoming semi-trailer truck or rail car and loading these materiels directly into outbound trucks, trailers, or rail cars, with little or no storage in between. This may be done to change type of conveyance, to sort materiel intended for different destinations, or to combine materiel from different origins into transport vehicles (or containers) with the same, or similar destination. Cross-Dock operations were first pioneered in the US trucking industry in the 1930s, and have been in continuous use in LTL (less-than- truckload shipping) operations ever since. The US Military began utilizing cross-dock operations in the 1950s. Wal-Mart began utilizing cross-docking in the retail sector in the late 1980s.

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  - Repair issues with potentially stochastic repair duration time; including unexpected sudden changes in conditions of vehicles
  - Depots
  - Vehicle capacity (maximum load allowed; weight, volume)
  - Compatibility between vehicles and loads
- Demand and requests/ orders
  - Regular orders based on replenishment plan and demand: known-in-advance
  - Requests with time windows or within a certain time period
  - Order priorities: urgent, essential, routine, replenishment (pg. 17, Tactical Logistics Report)
  - Unexpected sudden changes in demand (surge)
  - For the stochastic aspects of the demand, see Section 4.2.2
  - Note that in the past, when the system became clogged, and deliveries were coming late on the regular bases, the majority of orders start becoming urgent. Possible remedy: closely monitor delivery times and regularly communicate the up-to-date expected delivery times to all nodes of the SCN.
- Inventories and Loads
  - Heterogeneous goods
  - Small, medium, large, and very large
  - Vehicle compatibility: some requires special handling (refrigerators, special equipment for handling, etc.)
  - Goods compatibility: Some goods cannot travel with other goods:
    - Food rations and packaged POL products never travel in the same vehicle.
    - Certain trucks or task vehicles become assigned to specific commodities and they vary very slightly from their purposes, e.g., fuel truck.
    - Perishable goods.
- Travel times
  - Regular (deterministic or stochastic)
  - Unexpected sudden changes
- Loading/ unloading time – service time at a node:
  - May vary.
  - May require specialized equipment that might be unavailable because, *e.g.*, busy with another unloading/ loading operation, at repair shop, or some other reason.

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    - At each intermediate node, packing and re-packing may be required and it will require time and resources.
- Safety
    - Transportation vehicles traveling between APOD and FOBs often require protection vehicles to accompany them, and this implies need for convoys. The convoy consists of 7-8 or even 10 vehicles, out of which 4-7 are transportation vehicles and others are protection. Usually: one or two vehicles are for POLs, one vehicle is for water/ food, and one or two vehicles are for the military operation consumable materiel (see Section 5.5).
    - Potential multi-role of a UAV having transportation and reconnaissance roles (upcoming feature)
- Transportation networks: each edge has
    - Distance
    - Travel time that could be stochastic; travel times could be such that they do not satisfy the triangular inequality
    - Cost (associated with mileage, time, fuel, journey, load, and potentially safety)
    - Safety issues/ Risks associated with each edge/ node

If working in an urban environment, the city network can first be converted to a graph whose nodes are the pickup and destination nodes. Each edge in the graph represents the shortest or the safest path. The edge weight may change through time. We can also decide to have multiple edges with separate weights between two nodes to model different criteria.

4.2.2 Stochastic problem characteristics

Problem characteristics that potentially could be stochastic:

- Demand – being more stochastic going from left to right in the SCN
- Travel times – being more stochastic going from left to right in the SCN
- Safety/risk – risk being higher and more stochastic going from left to right in the SCN
- Goods lost in transit or in a warehouse

It is almost certain that the demand will be stochastic in our initial definition of the problem. The ‘pull’ system that is currently used is demand-responsive, and the newest trends are to try to migrate towards a ‘push’ system where forecasting and the stochastic nature of demand play a more important role.

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Known classes of probability distributions could be considered for simplification purposes. If the model allows, we would consider providing a user with the ability to change the probability parameters (average and variance).

We will also provide a model with deterministic demand as well, and we will use it for modeling regular replenishment planning in situations when demand for certain goods does not change. This deterministic model will also be used for comparisons with a stochastic model in an experimental study.

In addition to demand, we will choose one or two more problem features and provide possibility to make them stochastic, too. This will provide the solver with a capability to solve several versions of the supply chain management problem.

The most challenging would be forecasting of demand, and forecasting of in-transit and inventory handling of the following supplies:

- Medical supplies in chaotic disaster relief situations and
- Military operation consumable materiel in hostile military operations

4.2.3 Metrics/ Measures of Performance

In logistics, the most commonly used metrics are:

- Time to deliver. Note that with better forecasts, it is possible to order in advance and time to deliver becomes less critical.
- Stock-outs
- Inventory costs
- Delivery costs
- Distance
- Materiel quality
- Service level (percentage of satisfied demands vs. time)

In our scenarios, it is important to avoid stock-outs, to distribute the supplies proportional to the needs, and to travel along less risky routes.

One or more of the listed metrics would be used to define objective function(s) when solving the selected optimization problem. Others would be considered as constraints.

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4.3 Assumptions

This section lists the assumptions on which we will rely when solving the selected supply chain management problem:

1. Distribution Network Structure and Configuration is given: a number and location of suppliers, production facilities, distribution centers, warehouses, cross-docks and customers. (Confirmed by TA Jean Berger, in Jan 24 e-mail)
2. Distribution strategy is centralized. Potential existence of different service providers and vehicle fleet owners might be considered at a later stage of this project, by assuming multiple depots at the same level of the network.
3. Re-fueling issues will not be considered
4. The following logistics activities will not be considered:
    - Recovery of damaged vehicles
    - Urgent direct flight from APOD beyond FOBs
    - Hazardous material transport

    These activities and events could be modeled as 'vehicle is not available during the prescribed time interval' and potentially with a stochastic fleet size, if needed. Although, there is no need to consider these activities at all when fleet size is large enough.
5. Because the vehicle fleet size is large enough, we will not consider the stochastic nature of:
    - Vehicle unavailability due to repair
    - Repair duration
    - Fleet size due to assignment to other activities
        - Recovery of damaged vehicles
        - Urgent direct flight from APOD beyond FOBs
        - Hazardous material transport
6. RFID system is 'in the plans but unknown when it will be available' – to be dealt with by introducing stochastic nature of the supplies lost in transport or in a warehouse.
7. It is assumed that there are tracking devices on transportation assets based on the following information related to visibility and real-time monitoring of transportation assets and support equipment:

    > "Dealing with these issues can be measured through the success of two CF initiatives: DTAV and DRIMIS. DTAV – Defence Total Asset Visibility is the earlier initiative and it has been folded into DRMIS. DRMIS is the best example of TAV in the CF today. At present it supports the entire engineering and maintenance

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support function of the Royal Canadian Navy, 95% of the engineering and maintenance function of the Canadian Army and 30% of the same function for the Royal Canadian Air Force. By the end of 2013, engineering, maintenance and supply chain processes are supposed to be fully online and available in the DRMIS, enterprise wide solution across all three environments. Without the RFID capacity; though it does leave a gap in the enterprise solution when shipments depart for theatre." (As per SME John Conrad)

8. Since the following will not be modeled explicitly, perturbation in demand could be later used to model:
   - Materiel provided to other nation by DND – increase in demand
   - Materiel provided by other nations to DND – decrease in demand
9. Other problems that will not be considered in this project:
   - Bin packing for filling up the vehicles/ aircrafts, *i.e.*, planning of the loading of packages into trucks/ aircrafts.
   - Scheduling and routing of protection support vehicles and staff.
   - Possible multi-role of a UAV to ensure transportation and some form of protection (due to reconnaissance capability)
   - Scheduling of regular maintenance of vehicles so that there is very few periods when more than one vehicle is unavailable due to regular maintenance.
10. We could assume one unit of volume for all different types of loads. For example, Water Pallet EQuivalent (WPEQ): One 40"x48"x48" pallet of bottled water is approximately 2100lbs ≈ 0.95 tonnes (101.6cm x 121.92cm x 121.92cm ≈ 1m x 1.2m x 1.2m ≈ 1.44 m^3).
11. Information Flow is assumed to be resolved and that all information is known to all interested parties.
12. Cash-Flow is assumed to be resolved.
13. The problem of arranging and re-arranging the containers in the receiving yard at APOD will not be considered.

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5 SCENARIO

As already discussed in Section 3, the problems defined and characterized in Section 3 could arise in both disaster relief and military operations.

We plan to develop a disaster relief scenario from the material presented in this section that represents a peace-keeping scenario. Note that the data gathering is not finalized and some remaining questions in this section are to be resolved at a later date.

We will keep in mind that beyond the realism, the scenarios must present a challenge in terms of tempo, number of demands, short time intervals, etc. If needed, we will generate some random problems instances, for the demonstration purposes.

Table 5-1 compares some logistics scenarios and its logistics problem characteristics.

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Table 5-1 Logistics Scenario Examples and Their Similarities and Differences

Logistics Scenarios Examples	Tight constraints	Objectives	Vehicle Fleet	Network	Stochastic	Fluctuating Demand
Commercial/ Retail	Vehicle fleet Warehouse capacities	Min cost	Fixed size Homogenous	Stable and predictable travel times	Demand Travel times	Yes, but not very high variability
Mega-Earthquake	Supplies (medical, water, food) Transportation network Warehouse capacities; gradually decreasing from left to right in the SCN	Min risk Min losses of supplies	Not tight constraint Heterogeneous	Variable travel times Risks Not entire network available	Demand Travel times Lost supplies Risks	High variability
Man-made disaster: virus spread/ disease outbreak	Supplies (medical) Warehouse capacities	Min risk Min losses of supplies	Not tight constraint Heterogeneous	Variable travel times Risks	Demand Travel times Lost supplies Risks	High variability
Peace-keeping	Supplies (POLs, equipment, medical) Transportation network Warehouse capacities	Min risk Min losses of supplies	Not tight constraint Heterogeneous	Variable travel times Risks Not entire network available	Demand Travel times Lost supplies Risks	High variability

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5.1 The SCN structure

The potential structures of SCN are given in Section 3.3. There are one or two supply nodes, three FOBs, and two to four 'customer' nodes served by each FOB.

In terms of size of the tactical SCN:

- Military operation: no more than 3 FOBs is desirable.
- Disaster relief: for example, large earthquake in BC:

> "Major Bases for BC would be Calgary or Edmonton airports. In BC there might be one or two main centers (APOD) depending on the survivability of the airports. There will be probably 3 FOBs." (As per SME John Conrad)

5.2 Distances, Travel Times, and Frequency of Transport

Approximate desirable distances between APOD and FOBs are the distances that could be travelled back and forth without re-fueling and within 5-10 hours. In military operations, it would be desirable that the trip back and forth could be done during the night.

The most common distances are 40-50km, and sometimes up to 100km. Maximum distance was 300-350km.

Travel times APOD-FOB1-FOB2…-APOD: 3-4 days. These trips would repeat approximately every 7 days.

Travel times can deviate very much from average. By how much it can deviate from average?

Frequency of transport between APOD and FOBs should be daily. The only reason why it is sometimes less frequent is to increase transport safety in hostile environments.

JTF (Figure 3-2) can consist of three echelons known as A2, A1 and F, in which case the frequency of transport between these echelons would be as follows:

- Daily transport between FOBs and A2 echelon
- Hourly transport between A2 and A1 echelons
- From moment to moment transport between A1 and F echelons

A basic load of 3 days of consumable supplies is spread over F, A1, and A2 echelons, and 15 days of clothes, boots, and spare parts.

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5.3 Transportation Assets

Transportation assets used in CF include:

- Existing fleet of HLVWs (Heavy Logistic Vehicle Wheeled) vehicles
- New fleet of AHSVSs (Armoured Heavy Support Vehicle System) vehicles
- LAVs (Light Armoured Vehicle)

Table 5-2 CF Logistics Vehicle Capacities

Vehicle type	Capacity
HLVW	16 tonnes
AHSVS	23 tonnes
LAV	

According to the latest missions, in-theatre CF commonly uses around 120 – 150 vehicles, in total.

Newest additions to the CF fleet of vehicles are 82 AHSVSs out of which 25 are cargo vehicles with material handling crane. Approximately 70 vehicles are used for logistics activities with the following roles:

- 5 vehicles are recovery vehicles
- 5 vehicles are for bulk water transport
- 10 vehicles are for bulk POLs transport
- 40 vehicles have Palletized Loading System (PLS) with container handling unit
- 12 vehicles are heavy tank transporters

Out of total 120-150 vehicles in-theatre, Task Force uses approximately 70-80 vehicles: 45 LAVs, 12 HLVW or AHSVS vehicles, and 15-20 vehicles equipped for protecting the supply delivery convoys.

NSE Fleet of Vehicles: NSE (Tactical Logistics) uses around 30-50 vehicles, mostly AHSVSs and HLVWs:

- 20-25 for replenishment,
- 3 recovery vehicles,
- few communication vehicles,
- few maintenance vehicles, etc.

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Out of 20-25 vehicles used for replenishment, the roles are the following:

- 5 vehicles are for bulk water transport
- 8-10 vehicles (HLVW or AHSVS) are for bulk POL transport. Some of these fuel vehicles would have large fuel pods, and some would be configured to carry packaged POL products: oil, grease, brake fluids, other miscellaneous products and distillates that vehicles require.
- 6 vehicles for water and rations (food)
- 5 vehicles for general and technical stores
- 6 vehicles for equipment and the military operation consumable materiel

Note that with the palletized loading system (PLS) using easily droppable containers, the vehicles used for rations and other types of supplies are somewhat interchangeable. The only exception is the truck for the military operation consumable materiel that has additional safety features like fire extinguishers and static straps to neutralize electro static charge.

Fuel consumption example: Canadian LAV III fuel container capacity is 300 litres, and the vehicle can travel with this amount of fuel approximately 450 km.

Loading and unloading times: "During the cold war, a 'cross load' would take approximately 30 minutes. In the last several decades, the use of PLS Sea containers has resulted in much faster loading /unloading times." We can assume that 5-15 minutes are needed for container unload, while a container load may require 20-40 minutes? "However, pumping fuel takes 30 minutes to an hour." (John Conrad).

5.4 Supplies Variety and its Origin

There are 36,000 'line items' – types of supplies/ goods/ materiel.

Their grouping and location of origin are given in Section 3.3

5.5 Demand

Most of the demand during military operations is for POLs, water, food, and military operation consumable materiel. Compared to this, transportation of people seems to be negligible (as per John Conrad).

Stated logistics fleet size (Section 5.3) can support around 2,500 soldiers during a military operation and needs around 450 logistic staff (including the staff not involved in inventory and transportation activities).

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Table 5-3 Demand Through History

Time	Soldiers	NSE Staff	Supply Demand per day	Number of Loads/Trips per day (20t per vehicle)
WWI	20,000	5,000-7,000[†]	150 tonnes	Approximately 7 trips with AHSVS, or 10 trips with HLVW
WWII	18,000-20,000	9,000[‡]	650 tonnes	Approximately 29 loads of AHSVS or 41 loads of HLVW
Recent	2,500[§]	450[**]	20 – 40 tonnes	4-5 trucks (due to vehicle specialization and load incompatibilities)

Daily demand per person is as follows:

- 10-15 liters of water
- 3 meals

One FOB supports 1 Infantry Company which is around 150 soldiers, and there are usually 3 FOBs. These figures and a comparison with the 2,500 soldiers in Table 5-3 will be confirmed after consultation with our SME, John Conrad.

Fuel is needed for moving and air-conditioning. Each Infantry Company has around 15 LAV vehicles.

Note that out of the fuel that arrives at APOD, around 20% is spent at APOD and 80% beyond APOD.

In a transportation convoy traveling from APOD to a FOB, 4-5 replenishment vehicles would consist of:

- 2 bulk fuel vehicles: If all LAVs in a company were completely empty, the company would need (15 LAVs x 300 litres=4500 litres) for fuel replenishment. If there are four companies, this would come to around 18 tonnes of fuel. For transporting this, two HLVW 16 tonne trucks would be required.
- 3 PLS vehicles:

[†] "The sustainment system was different in the Great War having just collapsed/failed at the Battle of the Somme in 1916. I am extrapolating the number of support soldiers for the Canadian Division of 1917-18 with this figure." John Conrad

[‡] The Canadian Division in World War II required 9,000 army-level British support soldiers for logistic support. The source for this data is Canadian Forces College Lecture, C/JC/CPT 303/LE-30. The army of 1939 became mechanized which increased the demand for logistics support and its support base.

[§] "The modern battlefield is partially defined by the absence of machinery, long and widely dispersed operations. The deployment of a battle group or task force would be almost a negligible mention in a WW II context but in the 21st Century a Task force of 2,500 with a modern mechanized battle group has analogous strategic impact to a full up division of the World Wars" John Conrad

[**] The NSE grew from 281 in 2006 (with no contractors on the APOD) to more than 450 and 150 contractors in 2008.

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- 1-2 for water, food, and technical stores
- 1-2 for the military operation consumable materiel: "The consumption rate is much more variable depending on what it going on tactically. I would say two trucks would be assigned."

5.6 RFID and Lost Goods

We will introduce percentage of supplies lost in transport and warehouses as follows:

- Without RFID, this percentage will be 20% or a random number between 10% and 25%.
- With partial introduction of RFID, this percentage will be 10% or a random percentage between 5% and 15%.
- With fully introduced RFID system, this percentage can be 3%, or a random number between 0% and 5%.

These figures are preliminary and will be confirmed after consultation with our SME, John Conrad.

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