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MODELING AND SIMULATION OF CANADIAN FORCES STRATEGIC LIFT STRATEGIES

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ABSTRACT

In support of Canadian Forces (CF) transformation, a study was conducted to explore strategic lift movement strategies within the context of rapid deployability to counter asymmetric threats in failed or failing states around the globe. This study makes extensive use of two interconnected models. An aircraft loading optimization model using a combination of simulated annealing and genetic algorithm techniques with a novel convex hull based measure of effectiveness was developed to derive near-optimal loading plans across a fleet of transportation assets. The output from the loading model was then fed into a Monte Carlo simulation framework developed to allow for study of the effectiveness of a variety of strategic lift options. Analysis indicates that pre-positioning of equipment at various international locations and increased use of C-17 aircraft for airlift—where economically viable—could be potential strategies for improvement of the CF strategic lift.

1 INTRODUCTION

The Department of National Defence has been working on ways to ensure that it can handle the requirement of rapid deployability to meet its defence and security mandate. One of the recurring challenges has been determining strategic logistics lift requirements for deployed operations. The focus of this paper is on modeling and analysis of strategic lift movement strategies within the context of rapid deployablity to counter asymmetric threats in failed or failing states around the globe.

Strategic lift is required to various extents throughout the deployment, sustainment, and redeployment phases of a mission. Deployment is frequently the most difficult phase of a mission, as asset availability and closure time constraints are both very much in play (Guéret et al. 2003). In contrast, the Canadian Forces (CF) has historically been able to sustain missions through a mix of organic and contracted lift without major difficulty; in the case of redeployment, where time is generally not an issue, sealift, where at all practicable, has been used to reduce transportation costs.

Given that the nature of conflict has changed and the probability of more conflict flare-ups has increased, the capability to respond rapidly will be key. Such responses place heavy demands on airlift. Therefore, the challenge is to find the right mix of lift capabilities to support modern conflict response with possible augmentation via strategic pre-positioning on land or sea. This study will determine the performance of the CF's historical mission strategy over a simulated three-year interval; once this baseline has been determined, various risk mitigation and cost avoidance strategies will be explored to determine potential avenues for improvement of the CF strategic lift strategy.

This paper is organized as follows. The Section 2 presents the methodology for analyzing the strategic lift strategies. Section 3 discusses the mathematical formulation of the lift problem and presents the lift algorithm. Section 4 addresses the analysis of the performance of the different lift strategies. Concluding remarks are found in Section 5.

2 METHODOLOGY

To tackle the strategic lift problem, a simulation-based optimization approach was considered. Two interconnected models were developed—an optimization model to determine the transportation requirements for different airlift scenarios and a strategic lift simulation model was developed to analyze potential CF deployments to failed or failing states around the globe.

2.1 Strategic Lift Simulation

A Monte Carlo simulation framework was developed and implemented using the MATLAB software suite. The framework allows for study of the effectiveness of a variety of strategic lift options. To facilitate comparisons between different options, the framework establishes a common set of parameters describing a "typical" three-year period; within this framework, individual parameters such as locations of deployments, frequency of sustainment flights, aircraft flying times, etc., are then generated stochastically. To allow for meaningful statistical evaluation, measures of effectiveness for each strategic lift option are collected for each of 50,000 randomly generated three-year intervals.

Each randomly generated three-year time period within the simulation framework follows a common pattern (Figure 1). At the beginning of the simulation, a battle group is already deployed in a country randomly selected from a set of failed or failing states (Figure 2) based on a ranking developed by foreignpolicy.com. This battle group will then redeploy to Canada at some randomly selected point in time during the simulation. A second battle group will deploy to another randomly selected failed or failing state at a randomly selected point in time. A Disaster Assistance Relief Team (DART) deployment will also take place somewhere in the world over the course of the simulation. All deployed forces will be re-supplied via sustainment flights at a rate consistent with historical experience. All battle groups are based on the historical Operation (Op) ATHENA (Canada's Contribution to the International Security Assistance Force in Afghanistan) manifest, which requires the deployment of 350 military vehicles and 300 sea containers of supplies (Ghanmi 2004).

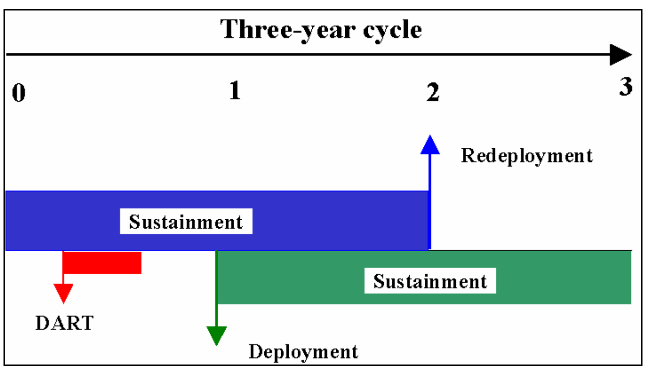

Figure 1: Scenario Framework

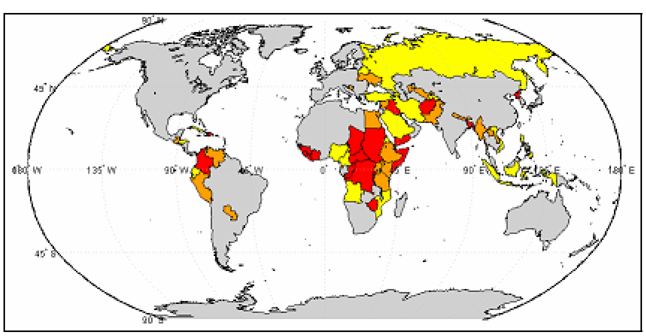

Figure 2: Failed or Failing States

2.2 Aircraft Loading Optimization

An aircraft loading optimization model was developed to determine the optimal mix of airlift capabilities required for future CF strategic deployments. The aircraft loading problem can be viewed as a two-dimensional bin-packing problem where a number of items (vehicles, containers, pallets, etc.) are loaded in bins (aircraft cargo bays) of a certain capacity. Aircraft loading is a multi-objective optimization problem—that is, we wish to determine the set of non-dominated solutions describing the distribution of loads across a variety of airlift assets. The problem has been shown to be NP-hard combinatorial optimization problem (Lodi, Martello, and Monaci 2002). Different approaches have been applied to address the bin-packing optimization problem, including simulated annealing (Eglese 1990) and genetic algorithm (Goldberg 1989) techniques.

Simulated Annealing (SA) approaches optimization problems by randomly generating a candidate solution, and then making successive random modifications. A temperature parameter is generally used to control the acceptance of modifications. Initially, the temperature is set at a high value and is decreased over time through an annealing schedule. SA performs random selection within an ever-shrinking local neighbourhood of the present candidate solution. The next candidate is accepted with a certain transition probability, which depends on the difference in fitness (a measure of solution goodness) and the temperature.

Genetic Algorithms (GAs) attempt to mimic the mechanisms of natural evolution to solve problems in a wide variety of domains. In contrast to simulated annealing, which iteratively refines a single solution vector as it searches for optima in a multi-dimensional landscape, GAs operate on entire populations of candidate solutions in parallel. In fact, the parallel nature of a GA's stochastic search is one of the main strengths of the genetic approach. This parallel nature implies that GAs are somewhat more likely to locate a global peak than traditional techniques, because they are less likely to get stuck at local optima. Also, due to the parallel nature of the stochastic search, the performance is much less sensitive to initial conditions.

In this paper, a hybrid method (Pakhira 2003) that combines the parallelism power of genetic algorithms and annealing schedule of simulated annealing is considered for solving the aircraft loading optimization problem. The algorithm, known as Genetic Annealing for Loading of Aircraft, a Heuristic Aiding Deployment (GALAHAD), introduces a SA type probabilistic selection procedure in the selection operator of genetic algorithms and applies the local temperature concept as a cooling schedule (Cho, Oh, and Choi 1998). The local temperature concept consists of assigning a fitness-based temperature to individual solutions, so that higher temperature is assigned to less fit individuals and vice versa. Thus, a less fit individual is given more chance to move uphill on the solution space for wider search whereas a fit one is given less chance of an uphill move for finer search to enhance the solution accuracy. GALAHAD also applies a novel convex hull based measure of effectiveness to derive near-optimal loading plans across a fleet of transportation assets.

2.3 Measure of Effectiveness

A variety of performance metrics are used to evaluate the effectiveness of various strategic lift options, including the cost and time associated with individual battle group and/or DART deployments, the cost of redeployment of either the battle group or the DART, and the costs associated with the sustainment of all deployed forces. The cost metrics in particular can be aggregated/studied over a broad range of time intervals and geographical areas.

2.4 Strategic Lift Strategies

The corresponding impacts of conducting strategic airlift directly from Canada, strategic pre-positioning in selected areas around the globe, or reconfiguring the manifest of equipment to be moved with alternative systems providing equivalent capability were determined relative to a baseline scenario based upon historical CF movement practices. The performance of each strategy was assessed using movement parameters such as lift cost and closure time.

2.4.1 Baseline Strategy

Based on historical practice, the baseline strategy considers a deployment by sealift from Montreal to an intermediate seaport of debarkation (SPOD), followed by an airlift to an airport of debarkation (APOD) at a given failed or failing states. Seven intermediate SPODs have considered: Derince, Turkey; Dakar, Senegal; Mombassa, Kenya; Dubai, UAE; Darwin, Australia; Singapore, Singapore; and Gauntanamo Bay, Cuba. These representative locations were selected for analysis purposes only, and do not necessarily reflect the likelihood of future use by the CF. The cost- and time-effective SPODs were determined for each deployment. For the redeployment phase, the lift time is generally not an issue and movement by sea is considered, where at all practicable, to reduce lift cost. Redeployment by sea is assumed for all failed or failing states situated in coastal areas. For landlocked states, the redeployment is assumed to be conducted by air to an intermediate transit location and then by sea to Canada. Sustainment and DART deployment are usually conducted by airlift from Trenton, Canada. Table 1 presents the historical Operation ATHENA airlift data used in the simulation.

Table 1: Operation ATHENA Airlift Data

Description	AN-124	IL-76
Maximum payload (tonnes)	80	35
Number of sorties	48	36
Charter Cost ($1000 US/hour)	23	10.5
Cruising Speed (km/hour)	700	650
Fleet (number of aircraft)	2	3

2.4.2 Pre-positioning

The study considered the impact of pre-positioning by dividing the Operation ATHENA manifest into two subsets. The first sub-manifest is assumed to be moved from Montreal in the historical manner, but the second sub-manifest is assumed to be pre-positioned at a given strategic pre-positioning location. Three international locations have been identified and explored for potential pre-positioning of equipment and supplies: Catania, Italy; Dakar, Senegal; and Dubai, UAE. As with the intermediate SPODs, these representative locations were selected for analysis purposes only. In addition to studying the optimal pre-positioning location, an analysis was also conducted to determine the optimal subset of the manifest to pre-position overseas. Three potential pre-positioning options were considered:

- Heavy equipment, defined as those vehicles moved during Op ATHENA by AN-124, is pre-positioned;
- Light equipment, defined as those vehicles moved during Op ATHENA by IL-76, is pre-positioned, and;
- A generic subset of equipment is pre-positioned.

2.4.3 Strategic Airlift Directly From Canada

In this strategy, the deployment is assumed to be conducted from Trenton, Canada to an APOD at a given failed or failing state using a fleet of transport aircraft. Deployment lift scenarios involving different combinations of transport aircraft (AN-124, IL-76, C-17) were examined to determine the optimal fleet mix.

2.4.4 Impact of Manifest Reconfiguration

The manifest reconfiguration strategy addresses the impact of replacing some of the Operation ATHENA manifest items with equivalent systems providing equivalent capability. One such amendment could include replacing some of the Heavy Logistics Vehicle Wheeled (HLVW) trucks by the proposed new Medium Support Vehicle System (MSVS) trucks.

3 MODEL FORMULATION

This section presents the mathematical formulation and the lift algorithm of the simulation model.

3.1 Mathematical Formulation

For simplicity, we only present the mathematical formulation of the baseline strategy. The formulation of the remaining strategies can be found in (Ghanmi and Shaw 2006). Let:

SP = number of intermediate SPODs;
i = index of an individual SPOD ($i = 1, \ldots, SP$);
FFS = number of failed or failing states;
j = index of an individual failed or failing state ($j = 1, \ldots, FFS$);
AP = number of airports in each failed state;
k = index of an individual airport ($k = 1, \ldots, AP$);
$APOE_i$ = airport of embarkation within SPOD i;
$APOD_{jk}$ = airport of debarkation k at state j;
GD_{ijk} = great circle distance between $APOE_i$ and $APOD_{jk}$;
SC_i = sealift cost for the movement between Montreal seaport and SPOD i;
ST_i = sealift time for the movement between Montreal seaport and SPOD i;
AC_{ijk} = airlift cost for the movement between $APOE_i$ and $APOD_{jk}$;
AT_{ijk} = airlift time for the movement between $APOE_i$ and $APOD_{jk}$;
DC_{ijk} = total deployment lift cost for the movement between Montreal seaport and $APOD_{jk}$ through SPOD i;
DT_{ijk} = total deployment lift time for the movement between Montreal seaport and $APOD_{jk}$ through SPOD i;
M = number of deployment airlift asset types;
m = index of an individual airlift asset type ($m = 1, \ldots, M$);
AS_m = aircraft speed (km/h) for airlift asset m;
CR_m = chartering rate (US \$/h) for airlift asset m;
SR_m = number of sorties required for airlift asset m;
AC_m = number of aircraft of type m;
SD_{ijkm} = number of sorties per day for aircraft of type m using a distance GD_{ijk}.

Using the above notation, the total deployment cost and time can be formulated as follows:

$$DC_{ijk} = SC_i + AC_{ijk} = SC_i + \sum_{m=1}^{M} \frac{GD_{ijk}}{AS_m} CR_m SR_m \quad (1)$$

$$DT_{ijk} = ST_i + AT_{ijk} = ST_i + \max_m \frac{SR_m}{AC_m SD_{ijkm}} \quad (2)$$

3.2 Lift Algorithm

1. *Initialize model*
   Load the scenario parameters (list of failed or failing states, list of seaports and airports, lift asset parameters, maximum number of iterations, etc.)
2. *Start simulation*: Iter = 1; (Iter ≤ max Iter)
   Deploying operation
   a. Select a failed or failing state j
   b. Select an airport k for the state j
   c. Determine the optimal seaport of debarkation

   $$i_{opt} = \min \lfloor DC_{ijk} \rfloor, \; i = 1, 2, ..., SP \quad (3)$$

   d. Compute total deployment time and cost
   Redeploying operation
   a. Select a failed or failing state j'
   b. *If* (j' = Landlocked)
      i. Select an airport k' for the state j'
      ii. Determine the optimal seaport

      $$i'_{opt} = \min \lfloor DC_{i'j'k'} \rfloor, \; i' = 1, 2, ..., SP \quad (4)$$

      iii. Compute airlift time and cost
   c. *Else* (movement by sealift)
      iv. Select a seaport of embarkation for the state j'
      Endif
      v. Calculate the redeployment time and cost
   Sustainment
   a. Set the number of sustainment weeks
   b. Calculate the total sustainment cost
   DART
   a. Select randomly a state j'' and an airport k''
   b. Calculate deployment and sustainment cost
3. *Loop*: Iter++
4. *Measures of effectiveness*
   Evaluate performance metrics such as cost and time metrics aggregated by geographical area or by ports.

4 LIFT STRATEGIES ANALYSIS

This section presents the analysis of the lift strategies. The impact of different movement parameters such the number of slot times, pre-positioning locations, manifest pre-positioning type, and fleet mix are also explored.

4.1 Baseline Strategy

One of the lift issues addressed in this study is the determination of the effective SPOD for a given deployment. In the model, the cost effective SPOD is obtained by minimizing the total deployment cost and the time effective SPOD is determined my minimizing the total deployment time. However, other considerations and constraints beyond the scope of this study (policy, infrastructures in the port, security, local road transportation, etc.) can also affect the selection of a port during deployments. Figure 3 presents the cost effective SPODs grouped by ports for deployments using the baseline strategy to various APODs located with selected failed or failing states around the globe. Region 1 represents the airlift option direct from Trenton, Canada. For states within the African continent, Mombassa, Kenya (region 6) seems to be an effective and well located maritime transit location; Dakar, Senegal (region 3) is only optimal for a limited number of states in Western Africa. On the other hand, the port of Dubai, UAE (region 5) provides a potential strategic and effective SPOD for deployments to states in the Middle East and Southwest Asia. The port of Derince in Turkey (region 4) is also well located for deployments to states in Europe, North Asia, and some states in the Middle East. Figure 3 also indicates that the port of Darwin, Australia (region 8) is optimal for only one state in the region of Southeast Asia—most of the failed or failing states in that region are more clustered around the port of Singapore. For comparison purposes, the time effective SPODs for the baseline strategy is also presented in Figure 4. While there is substantial overlap between the cost- and time-effective choices of SPOD, notable differences exist. Figure 4 indicates that the seaports of Dakar, Derince, and Mombassa (regions 3, 4, and 6) are time effective for most of the failed or failing states in Africa, Europe, the Middle East, and Western Asia. Regions 2 and 5 are eliminated in the time-effective SPOD solutions as they are dominated by other regions.

Figure 3: Cost-Effective Intermediate SPODs

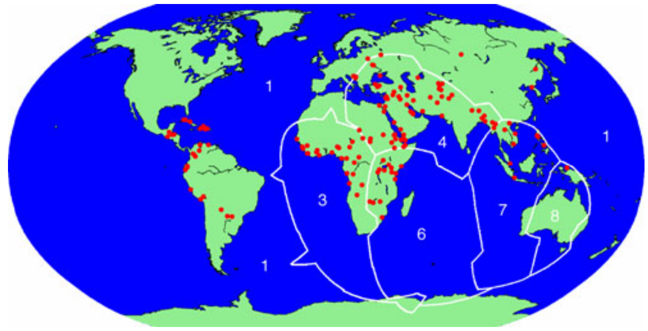

Figure 4: Time-Effective Intermediate SPODs

The costs and times associated with each deployment to failed or failing states vary considerably with geographic location. Figures 5 and 6 present respectively the mean deployment cost and time grouped by SPOD as well as the corresponding 95% confidence intervals. It is not possible to determine a confidence interval for Darwin, as it is the potentially optimal intermediate SPOD for only one APOD in one failed state. Over 50,000 simulated three-year intervals, the average deployment cost associated with deploying forces overseas using the baseline strategy was \$9.53 million US and the average deployment time was 42.5 days. In particular, the mean lift cost and time for deployments to states in Africa through Dakar or Mombassa seaport are respectively \$9.5 million US and 40 days. In average, between 25% and 30% of the lift cost is attributed to sealift and between 70% and 75% of the lift cost is associated to airlift. However, the sealift phase accounts for almost 60% of the deployment time. Similar ratios of sealift cost and time were also observed for deployments to Europe through Derince, the Middle East through Dubai and Southeast Asia through Singapore.

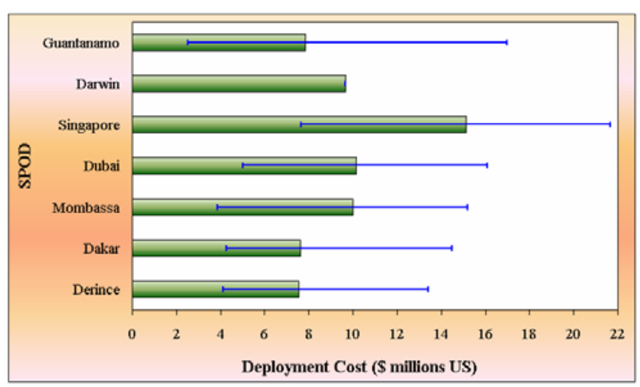

Figure 5: Expected Deployment Cost Grouped by SPOD

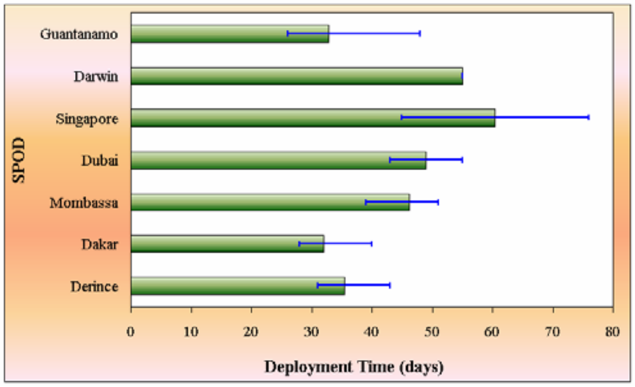

Figure 6: Expected Deployment Time Grouped by SPOD

Figure 7 presents the probability density of the total three-year scenario cost. The mean total scenario cost is \$95.3 million US, with a standard deviation of \$39 million US. The corresponding 95% confidence interval ranges from \$29.2 million to \$178.0 million US. Of this total, the costs associated with sustaining deployed forces account for \$76 million US or 80% of the total three-year scenario cost. The deployment cost accounts for 10%, the redeployment cost for 5%, and the DART deployment for 5% of the total three-year scenario cost. Sustaining forces is the critical phase of operation as airlift option is usually used to move supplies to theatre. Further analysis should be conducted to explore other potential lift options for reducing sustainment costs. Options could include increasing the proportion of sustainment conducted by sealift, increased use of C-17 aircraft or pre-positioning of supplies at different strategic locations.

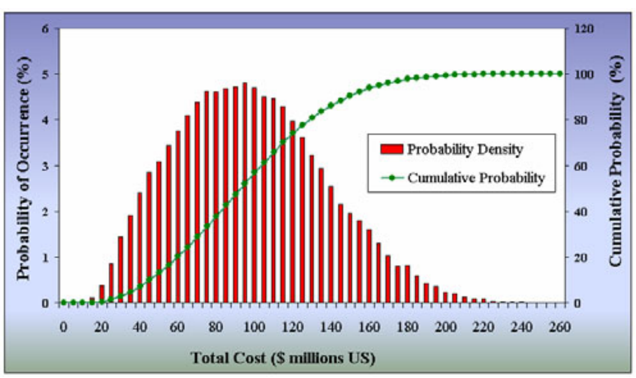

Figure 7: Total Cost Probability Density

4.2 Impact of Pre-positioning

Analysis was conducted to address the impact of pre-positioning location on deployment cost and time distributions; additional costs associated with maintaining pre-positioned equipment were not considered in this study. Figure 8 presents the mean deployment cost and the mean movement time for pre-positioning a generic subset of Operation ATHENA manifest at different locations. All three pre-positioning locations considered afford some benefit in terms of reduced deployment cost and time, but Catania, Italy and Dubai, UAE represent the time- and cost-effective pre-positioning locations, respectively. In particular, pre-positioning in the UAE would offer additional cost avoidance upon deployment of \$50,000 at the cost of requiring an extra half day to complete the movement. Given the geographical distribution of the failed or failing states, the analysis appears to indicate that areas in the vicinity of either the UAE or Italy could be potential strategic locations for pre-positioning a subset of Operation ATHENA manifest in order to reduce lift cost and time.

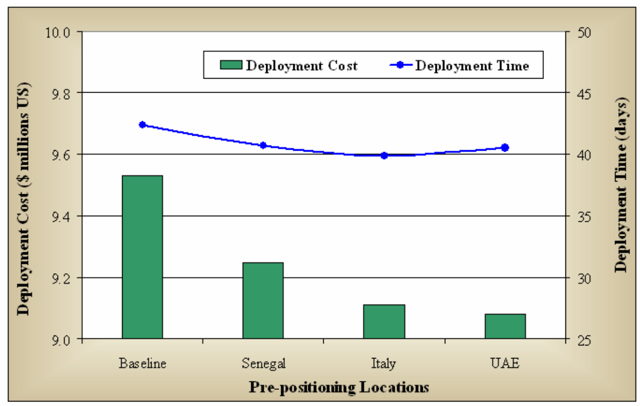

Figure 8: Mean Deployment Cost and Time for Different Pre-positioning Locations

Deployment cost and time are also impacted by the composition of the pre-positioned subset of the Op ATHENA manifest. Figure 9 shows the impact of pre-positioning three different ATHENA subsets in the UAE. The baseline and generic options are identical to those presented in Figure 8, while the “Light” and “Heavy” options correspond to pre-positioning those vehicles that were historically moved by IL-76 or AN-124, respectively. While all choices of pre-positioned equipment afford some savings in terms of cost and time, the heavy pre-positioning option represents both the cost- and time-effective option, with a savings of \$450,000 US and 7 days with respect to the historical baseline. This is not altogether surprising, since the historical movement solution requires 48 AN-124 loads (18 loads of vehicles and 30 loads of containers of supplies) to be moved using only two aircraft; pre-positioning the AN-124 vehicle loads allows these items to be deployed while the remainder of the manifest is still at sea. While a similar head-start can be obtained by pre-positioning the light IL-76 loads, the impact is not as significant, as the number of IL-76 loads does not constitute the binding constraint on the movement.

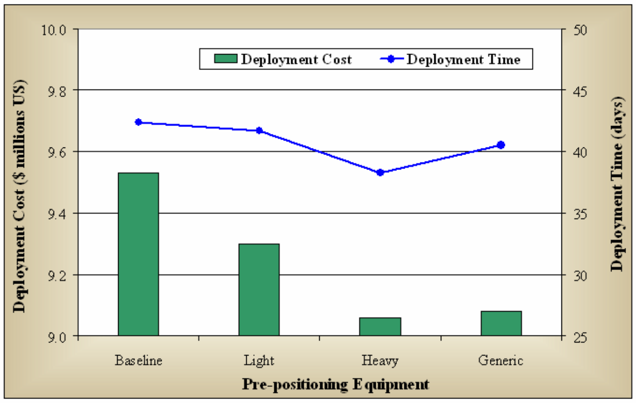

Figure 9: Mean Deployment Cost and Time for Different Manifest Pre-positioning Options

4.3 Strategic Airlift Directly From Canada

This section presents and discusses the results obtained from analysis of strategies involving strategic airlift direct from Canada; the deployment is assumed to be conducted by airlift from Trenton to an APOD at a given failed or failing state. The impact of the airlift fleet mix and the number of slot times available at the destination APOD on the overall movement cost and time was examined.

Three potential fleet mixes have been analyzed and compared with the historical airlift option:

- *Op ATHENA Historical*: Deployment conducted using a fleet of two AN-124s and three IL-76s;
- *AN-124 & C-17*: Deployment conducted using a fleet of two AN-124s and five C-17s; and,
- *C-17 & IL-76*: Deployment conducted using a fleet of five C-17s and three IL-76s.

In cases involving airlift using C-17s, costs are calculated based on the charter rates charged by the United States Air Force (USAF) during Op APOLLO (Canada's first deployment to Afghanistan in early 2002). While using these cost figures facilitates analysis, it should be stressed that Canada was the beneficiary of a very favourable chartering agreement in this particular case; future chartering costs—or costs associated with owning and operating a small fleet of integral C-17s—could be significantly higher.

Analysis was conducted using GALAHAD to determine the set of non-dominated fleet loading solutions for the Op ATHENA manifest of equipment and supplies for each of the three fleets listed above. For each simulated scenario, the corresponding deployment costs and times were computed for each of the loading solutions generated by GALAHAD.

Figure 10 illustrates the resulting deployment cost and time combinations obtained for all loading solutions in one such scenario. Considerable variation in both cost and time is observed depending on the particular choice of loading solution.

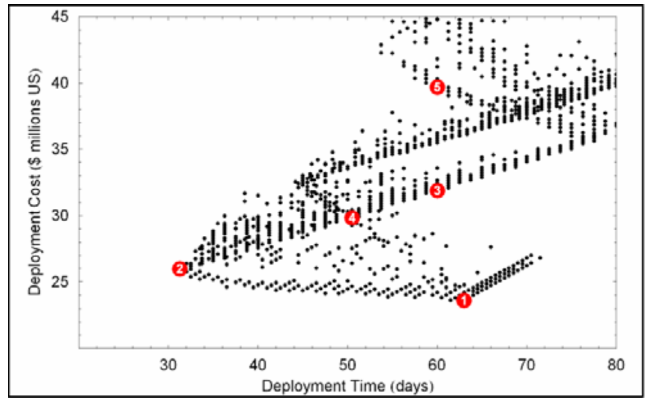

Figure 10: Overall Deployment Costs and Times Associated with Various Fleet Mixes

Five particular choices of loading solution are highlighted in Figure 10. For each solution, the specific number of loads allocated to each airlift asset type is listed in Table 2. Option 1 represents the cost-effective loading solution, which utilizes 126 C-17 loads to allow the movement to be completed in 63 days at a cost of $23.6 million US. Similarly, Option 2 is the time-effective solution, allowing for movement in only 31.3 days at a cost of $26.0 million. The solutions lying along the line connecting Options 1 and 2 represent the efficient frontier—those solutions representing the optimal tradeoff between the competing goals of minimizing both deployment cost and time.

Table 2: Number of Sorties Required for Each Option.

Option	Description	AN-124	IL-76	C-17
1	Cost Effective	0	0	126
2	Time Effective	25	0	62
3	C-17 & AN-124	48	0	23
4	C-17 & IL-76	0	36	100
5	Historical	48	36	0

The three remaining options shown in Figure 10 are suboptimal, as they do not lie on the efficient frontier, although Options 4 and 5 would lie on the efficient frontier for problems in which AN-124 or C-17 assets were not available, respectively. Option 5 represents the actual load solution utilized in the Op ATHENA deployment. Options 3 and 4 are derived from the historical solution by the replacement, respectively, of the IL-76 or AN-124 assets with C-17s.

Figure 11 presents the aggregate results of the analysis over all 50,000 scenarios and compares the deployment cost and time for each of the fleet mix options presented in Table 2. While the overall performance of each option is generally comparable to that illustrated for the particular scenario chosen in Figure 10, there are slight differences.

Conducting strategic airlift directly from Canada using the historical Op ATHENA loading solution would cost $38 million US and require 63 days. Option 1 remains the cost-effective option, requiring 59 days to complete the move at a cost of $23 million US. For an additional $3 million US, this can be shortened to 29 days through increased use of chartered AN-124 assets. As was the case in Figure 2, neither Option 3 nor Option 4 provide any benefit relative to the cost-and time-effective solutions presented here.

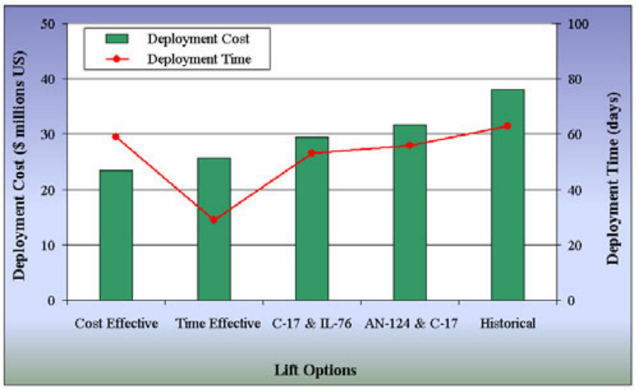

Figure 11: Impact of Airlift Fleet on Deployment Cost and Time for Airlift Directly From Canada

All of the preceding analysis has implicitly assumed that we are free to land aircraft at our destination as many times in a day as the size of our airlift fleet will allow; i.e., our deployment time is constrained only by the number of available aircraft. However, many recent CF deployments have been within large multi-national efforts; correspondingly, each nation is allocated a fixed number of "slots" in which they are allowed to land aircraft. Figure 12 illustrates the changes in the shape of the efficient frontier that occur as the number of aircraft that can be landed at the APOD per day increases from one to three for the choice of movement scenario and airlift fleet composition as was used in Figure 10.

With three or more slot times at the destination, there is no impact on movement time or cost—the number and types of aircraft available provide the binding constraint. If the number of available slots is reduced to two, the movement can no longer be completed in less than 40 days, and even so at significantly higher cost than was possible in the unconstrained case. With only one slot available, closure times are extended well beyond 60 days, with the cost-effective movement requiring 126 days to complete. The potentially dramatic savings in time and cost should clearly be kept in mind while negotiating the number of slot times allocated!

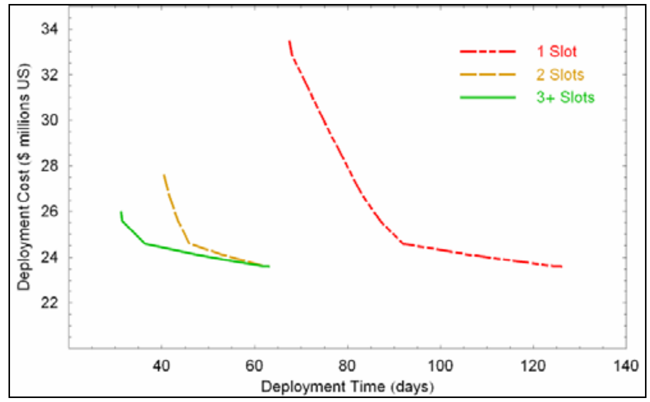

Figure 12: Impact of Slot Times on Deployment Cost and Time for Airlift Directly From Canada

4.4 Impact of Manifest Reconfiguration

This section presents the results of an analysis into the impact of replacing some of the equipment in the original Op ATHENA manifest with alternative systems providing equivalent capabilities. As an example, since the HLVW (the CF's standard 10 tonne truck) is not transportable by the CF's CC-130 tactical airlift assets, one might consider the replacement of some number of the HLVWs with the smaller 5 tonne MSVS trucks currently being considered for acquisition. Table 3 presents the vehicle characteristics for both the standard cargo (SC) and the load handling system (LHS).

Table 3: HLVW and MSVS Specifications.

Vehicle	Length (m)	Width (m)	Height (m)	Payload (Ton)
HLVW (SC)	9.18	2.55	3.65	9.6
MSVS (SC)	6.95	2.44	2.85	4.54
HLVW (LHS)	9.18	2.55	3.65	10
MSVS (LHS)	6.19	2.44	2.85	8

Determining how many MSVS are required to replace one HLVW is a non-trivial question. Both types of trucks are capable of carrying the same volume of cargo, but the HLVW is capable of substantially more weight. Consequently, Figure 13 demonstrates the sensitivity of the airlift asset requirements to a variety of replacement ratios. In the best case scenario, the cargo that the trucks are required to transport will bulk-out before weighing-out, and a one-for-one replacement of HLVW with MSVS is possible. Represented by the dashed green line in Figure 13, the smaller size of the MSVS saves a few aircraft loads across the entire range of asset mixes. However, this small benefit disappears rapidly if more than one MSVS is required for each HLVW. From a strategic airlift standpoint, then, there is at best only minimal benefit from this particular option for manifest reconfiguration; however, the increased tactical transportability of the MSVS will have to be weighed against this apparent additional strategic burden.

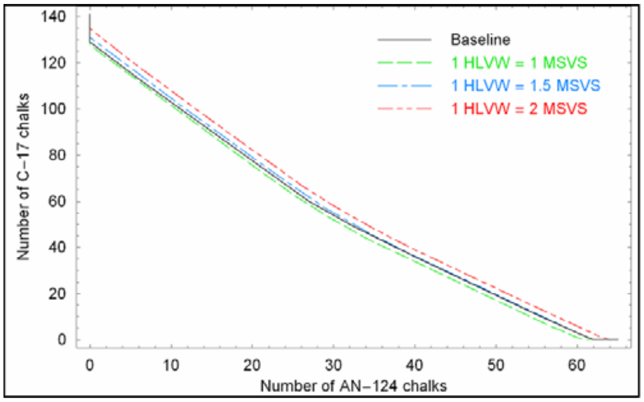

Figure 13: Impact of Manifest Reconfiguration on Transport Requirements

5 CONCLUSION

This paper presented a simulation-based optimization methodology to study potential future CF deployments to failed or failing states around the world. The methodology utilized two interconnected models—an aircraft loading optimization model used to determine the optimal airlift fleet mix and a Monte Carlo simulation model used to assess the effectiveness of a variety of lift strategies.

Different strategies were assessed using a variety of measures of effectiveness, including movement cost and time, optimal SPOD, optimal pre-positioning location, etc.. Analysis indicated that pre-positioning of selected equipment at strategic international locations offered the potential to reduce closure times with some small cost avoidance in the overall deployment cost. In particular, pre-positioning of heavy equipment (i.e., HLVW) in areas in or around Italy or the UAE appears to be the most effective pre-positioning option under both time and cost considerations.

The study also served to illustrate the potential advantages of increased use of C-17 assets in terms of both movement cost and time, particularly in cases where strategic airlift would be conducted directly from Canada. Further analysis is required on this point, however, as the cost figures utilized in the analysis were based on the highly favourable chartering rate of USAF assets used during Op APOLLO—any advantages may be reduced or eliminated if future chartering (or ownership) costs are significantly higher. The study also indicated that the number of airlift slot times available at destination has a significant impact on deployment time. Finally, from the perspective of strategic airlift only, the replacement of HLVWs with MSVSs in the original ATHENA manifest appeared unlikely to offer any significant benefits.

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