Simulating the Repatriation of Canadian Forces Materiel from Afghanistan

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Abstract: The Canadian Forces ceased combat operations in the Kandahar province of Afghanistan in 2011 and were instructed by the Government of Canada to complete its redeployment out of Kandahar by the end of December 2011. Materiel and equipment were transported back to Canada over several lines of communications. Nearly 1500 sea containers full of materiel, 800 vehicles, and 200 air pallets of material were returned to Canada by combinations of air, sea, and ground transport. This paper describes a discrete-event simulation model developed to analyze the repatriation of Canadian equipment from Afghanistan to Canada via the applicable lines of communication. The objective was to develop a model that could be used to analyze the repatriation in order to enable and improve future mission planning. The discrete-event simulation model is shown to be representative of the actual repatriation effort and is subsequently used to determine the impacts of different potential courses of action, measured mainly through results on the total cost and duration of the returns.

1 INTRODUCTION

In March 2008, the Government of Canada directed the Canadian Forces (CF) to cease combat operations in the Kandahar province of Afghanistan by July 2011, ending Operation ATHENA, Canada's 10 year contribution to NATO's International Security Assistance Force. The CF was instructed to complete its redeployment out of Kandahar by the end of December 2011 and a Mission Transition Task Force (MTTF) was set up to conduct the closure. MTTF planning commenced in early 2010. Materiel and equipment were transported back to Canada over several lines of communications (LOCs). Time, the sensitivity of material being shipped, threat and costs were the main factors used to determine the mode of transportation and the LOC that would be used for shipments from Afghanistan back to Canada. Sensitive materiel consisted of most vehicles, communications equipment, weapons systems, spare parts, munitions and high value items. Roughly 1500 sea containers, 800 vehicles, and 200 air pallets of material were transported by LOCs destined for Canada.

The main lines of communication were:

1. Air lines of communication (ALOC) from Kandahar direct to Canada or to Intermediate Staging Terminals (ISTs), referred to hereafter as *ALOC Direct* and *ALOC IST*, respectively. The IST was initially located in Cyprus and transitioned to Kuwait in September 2011. These ALOCs were used to retrograde material and vehicles that was deemed time or security sensitive[1]. The 1 Canadian Air Division devoted daily CC-177 Globemaster III airlift assets to support mission closure. Contracted Antonov AN-124 airlift was also employed to move large and heavy vehicles (such as main battle tanks). Restrictions were imposed on use of the AN-124 for the move of weapons systems, ammunition and classified materiel due to security considerations. Escorts were utilized on a number of flights to mitigate risk.
2. Ground lines of communication (GLOC) from Kandahar to Karachi, Pakistan. Contracted trucks were used to transport containers from Kandahar Airfield to the port of Karachi for onward movement by scheduled maritime liner service to Canada. Only non-sensitive materiel was transported through GLOC. During mission planning, this route represented the least costly LOC, but was potentially risky due to the possibility of

[1] Abiding by the request of the Cypriot Government, there would be no movement of Main Battles Tanks or ammunition and explosives through the island. The Kuwait IST provided no such restrictions.

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criminal activity along the route.

3. Sea lines of communication (SLOC) from Karachi or the IST back to Canada. Regularly scheduled liner service was used from Karachi to the Port of Montreal. Sea travel from Cyprus and Kuwait was done by four specially contracted ships. The International Port of Kuwait was used for the loading of materiel and vehicles while the Kuwait Naval Base provided a safe and secure area for the loading of ammunition.

The MTTF recorded and managed the retrograde operations with a spreadsheet-based tool that provided a common operating picture (COP). This was used as the primary planning tool and was updated daily—it provided a comprehensive listing of all vehicles, sea containers, ammunition, and general freight identified for retrograde, prioritized for movement along the applicable line of communication. The MTTF COP, while providing a wealth of detailed data such as vehicle/container weights, aircraft departure times and loads, etc., was limited with respect to assisting in options or predictive analyses.

1.1 Objective and Scope

This paper describes a discrete-event simulation model developed to analyze the repatriation of Canadian equipment from Afghanistan to Canada via the LOCs. The objective is to enable and improve future mission planning and to capture pertinent data recorded in the MTTF COP. Operation ATHENA MTTF was a large undertaking encapsulating several efforts. More than 2700 shipping containers and 1000 vehicles were processed, more than 250 structures/buildings were transfered, over 10000 contracts were reviewed/closed, over 7000 cubic meters of soil was remediated, 150 terabytes of electronic data was processed, and 120 thousand pounds of paper was repatriated.

The scope of discussion in this paper is focused on the equipment repatriated and the LOCs used for the repatriation. Naturally, several simplifying assumptions were made in the attempt to model reality. The paper is structured as follows: Section 2 provides references to tools and models published in the open literature and describes the discrete-event simulation model of the repatriation of Canadian equipment along the different LOCs. Section 3 compares the results of the baseline simulation model to reality (as captured in the MTTF COP), and subsequently Section 4 reports on results obtained from select scenarios deviating from the baseline. Actual cost figures are purposely omitted. Instead, results are reported as relative differences.

2 METHODOLOGY

Research into modelling military logistics has received much attention, benefiting from both simulation and optimization approaches.

Schank, Mattock, Sumner, Greenberg and Rothenberg (1991), and more recently Powell, Whisman and Wu (2009) provide a review of military logistic modelling efforts. They group the modelling approaches into deterministic linear programming, simulation, and stochastic programming categories (and furthermore propose a method to combine simulation and optimization). Primary focus has been on airlift modelling. Dantzig and Ferguson (1995) developed one of the earliest mathematical models for optimizing air-based transportation. Research at the United States Naval Postgraduate School (NPS) and the RAND Corporation were combined to create NRMO (NPS/RAND Mobility Optimizer) described by Baker, Morton, Rosenthal, and Williams (2002). The heart of NRMO is a linear programming model that minimizes the amount of cargo delivered late or not at all. Burke, Love and Macal (2004) developed the Transportation System Capability discrete-event simulation model to simulate the deployment of forces from U.S. Army bases. The U.S Air Mobility Command employs a rules-based simulation model called the Air Mobility Operations Simulator (AMOS) for strategic and theater operations to deploy military and commercial airlift assets.

Open literature publications from Defence Research and Development Canada include an aircraft load allocation optimization model (Ghanmi et al., 2009) which uses a hybrid of simulated annealing and genetic algorithm methods to solve a multi-objective optimization problem associated with allocating a set of cargo items across a heterogeneous fleet of available airlift assets. The model was used to conduct analysis of some of the strategic lift options for the Canadian Forces and to develop a simulation framework to study the effectiveness of a variety of pre-positioning options (Ghanmi and Shaw, 2008). Campbell and Moorhead (2010) developed a spreadsheet-based movement options analysis simulation tool useful for military move planners to determine rough time and cost estimates of strategic movement of materiel.

2.1 Discrete-event Simulation Model

A discrete-event simulation model was built in order to recreate the repatriation of materiel from Afghanistan to Canada via the LOCs. A discrete-event simulation was used over other techniques due to the inherent flexibility of simulation models, their ease in performing sensitivity analyses, and their ability to identify critical constraints in the system.

The model was built in the *Arena* simulation environment (Kelton et al., 2010). An *Arena* model is a computer program containing components called modules that represent processes or logic. Connector lines are used to join these modules together and specify the flow of entities. While modules have specific actions relative to entities, flow, and timing, the precise representation of each module and of each entity relative to real-life objects is subject to the modeller.

In this case, entities within the model represent the various items that are to be returned to Canada from Afghanistan. The lowest level of granularity of the items in the simulation are containers, vehicles, and air pallets – the specific contents in the containers or pallets are not specified. At the start of the simulation, all items (vehicles, containers, and so on) are created and placed at the Kandahar airfield. Upon creation, each of the items is assigned a specific method of shipment (or LOC) to use in its return to Canada, and are placed in LOC-specific queues.

Resources in the model representing the various modes of shipment govern the availability of the AN-124 and CC-177 aircraft used for the ALOCs, the contracted trucks used for the GLOC, and the ships used for the SLOC. Note that the data concerning these resources is in line with the historical availability of these resources.

Average temperatures in Afghanistan were between 20 ^{o}C and 35 ^{o}C at night in June to September and 45 ^{o}C or higher during the day. This affected the maximum payload (MPL) that could be loaded on aircraft, despite the fact that movement was preferred at night when temperatures were at their lowest.

Each day, available resources are loaded with items until they reach (but not exceed) their MPLs. The MPL of the AN-124s was computed as a function of the external air temperature, which was determined stochastically as a function of the simulation date through the use of historical payload data. However, data concerning the relationship between the payloads of the CC-177 and the external air temperature was not available – hence, the MPL of the CC-177 aircraft assets was determined by bootstrapping historical datasets of all monthly payloads of CC-177 flights departing Afghanistan.

Of particular note is the distinction for waiting times for the SLOC – upon arrival from the GLOC at Karachi, items depart for Canada via liner service; hence do not incur significant waiting times at port. Conversely, items at the IST depart via contracted sealift at specified dates. Items arriving at the IST for transport to Canada wait until the next scheduled ship departure date, incurring holding costs each day until they depart.

Each type of resource has its own specified distribution of the time required to reach its next destination (Canada, one of the ISTs, Karachi, etc.). As items travel along each of the LOCs, costs of each segment are determined stochastically, as are the durations for which the resources are travelling along the LOCs. At the end of the simulation, all costs are aggregated into a final figure for the entire cost of the MTTF.

As the model involves various stochastic elements, there was a need to perform multiple runs of the model in order to obtain a representative sample of the various outputs of the model. The results in this paper are based on 800 runs of the model (50 runs for each scenario discussed).

2.2 Data

Data used in this study was extracted from the MTTF COP spreadsheets (containing entries up to 28 November 2011) and consisted of item weights (containers, vehicles, and air pallets), flight times, aircraft loads (weight and number of items), and the LOC chosen for each item shipped. The MTTF COP records report on 757 vehicles, 1408 containers, and 170 air pallets shipped out of Afghanistan (the air pallets were shipped exclusively via ALOC Direct to Canada). To generate realistic weights for the simulation model, lognormal probability distribution functions (pdf) were fitted to the container and vehicle weights found in the MTTF COP data set. The mean container weight was $15,125$ pounds (lbs) and the pdf's standard deviation was $7,604$. Vehicles weights were found to be tri-modal due to the presence of very heavy vehicles over $100,000$ lbs (*e.g.*, tanks) and very light vehicles under $20,000$ lbs (*e.g.*, trailers). For use in the simulation model, three pdfs for light, medium, and heavy vehicle weights were fitted with means of $7,443$ lbs, $39,648$ lbs, and $126,531$ lbs respectively; and standard deviations of $7,078$ lbs, $13,123$ lbs, and $5,460$ lbs respectively. The weight of air pallets was set at $4,500$ lbs.

The MTTF COP reports on completed CC-177 flights out of Afghanistan as follows: 27 routed to Canada, 82 to Cyprus, 75 to Kuwait. It is useful to note that Cyprus was also used by the Canadian Forces for troop rotation referred to as "relief-in-place." CC-177 assets were used to transport over 1000 passengers out of Afghanistan. Nearly a quarter of CC-177 flights from Kandahar to Larnaca carried a significant number of passengers (over 40) and containers/vehicles. The MTTF COP reports on a

125 completed AN-124 flights from Kandahar to an IST and 11 routed to Canada. MTTF flights out of Afghanistan started in the first week of May 2011.

CF Move Planners provided cost information for contracts (AN-124 flights, GLOC trucks, chartered or merchant sealift). The Canadian Department of National Defence Cost Factors Manual was used to estimate the costs of using CC-177 assets native to the CF. Costs are not disclosed herein, however Figure 1(a) provides insight into the relative costs of using each of the different LOCs:

- ALOC Direct using an AN-124;
- ALOC Direct using a CC-177;
- ALOC IST using an AN-124;
- ALOC IST using a CC-177;
- Sealift from an IST;
- GLOC using a truck followed by sea liner service from Karachi.

All numbers in the figure are mean costs associated with each of the LOCs, and are expressed as fractions of the cost associated with the ALOC Direct method using a CC-177 aircraft.

Since each method of shipment can carry a different number of items, the costs of transporting an individual container back to Canada are illustrated in Figure 1(b), calculated under the assumption of full loads aboard each of the different vessels. In this figure the costs of the ALOC IST and the subsequent sealift portion of the return are combined into one expression.

In simple terms, the different LOCs have widely varying costs per container. The costs of travelling directly to Canada via airlift are slightly more than double the costs of travelling to an IST via airlift and using sealift to return to Canada; and the costs of forgoing airlift at all and using the GLOC and subsequent sea liner service is approximately fifteen times cheaper than the IST option. Moreover, the costs of using contracted AN-124 airlift is slightly higher than using CC-177 airlift native to the CF.

2.3 Notable Assumptions and Limitations

In this section, the assumptions inherent in the data and the methodology are described in detail.

Materiel and Vehicle Processing in Kandahar. CF units handed over their equipment and vehicles to the MTTF over several months. Vehicle and materiel production lines were established to process and prepare the returns. Vehicles and containers were inspected, sent for maintenance/repair, and fumigated. All materiel was tagged and grouped by shipping priority or destination and placed into containers. Vehicles and containers then were moved to the airfield or put aside for pick-up (by truck). These MTTF efforts within Kandahar were outside the scope of the analysis.

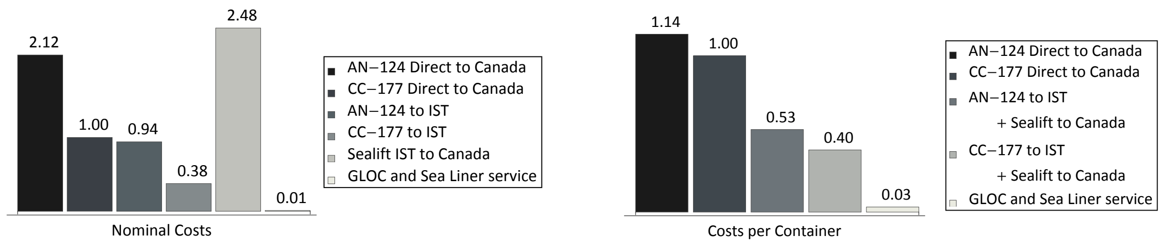
Modelling of Distribution within Canada. After arriving in Canada (either in Trenton if arriving by ALOC Direct, or in Montreal if arriving by sealift) the items were distributed amongst the various CF supply depots, facilities, and bases. However, no efforts were made to model the distribution of the items in Canada, as it was not within the scope of the analysis.

Disposal, Transfers, and Sales. A significant portion of non-essential items in Afghanistan used by the CF were disposed (*i.e.*, destroyed), transferred, or sold to external organizations (*e.g.*, foreign militaries, non-governmental organizations, etc.). These items were not modelled – the simulation only included those items which were to be returned to Canada.

Other Aircraft used in the Airlift. The model incorporates airlift handled by the CC-177 aircraft and the contracted AN-124 aircraft. However, there were other types of aircraft involved in the airlift to a much lesser extent – these included the CC-130 aircraft, which was primarily used to transport materiel from one location in Afghanistan to another; and the CC-150 aircraft, which was primarily used to transport personnel from Kandahar to the ISTs. As the model was focused on the return of materiel from Afghanistan these aircraft were not included in the model.

Equipment used by Op ATTENTION. Operation ATTENTION is Canada's participation in the NATO Training Mission - Afghanistan (NTM-A), which delivers training and professional development support to the national security forces of Afghanistan. The MTTF was directed to move a small portion of the materiel used by Operation ATHENA to another region of Afghanistan for use by Operation ATTENTION. As this materiel were not repatriated by the MTTF, they were not included in the model; nor was the airlift that was used for their movements (which included AN-124 and CC-130 aircraft).

Aircraft Payload: average vs. max. When determining the maximum payload able to be carried by the aircraft under the different temperature conditions, the *actual* payloads of the aircraft were used instead of their *maximum* payloads,



(a) The relative costs of the different LOCs.

(b) The relative costs per container of the different LOCs.

Figure 1: The relative nominal and per-container costs of the different LOCs are illustrated in Subfigures 1(a) and 1(b), respectively. All numbers in the figures are expressed as fractions of the ALOC Direct cost using a CC-177 aircraft, which is given a cost of 1.

which was unavailable to the authors. As the items loaded on the aircraft were discrete in number, the modelled payloads were necessarily smaller than they were in reality. The impacts of this assumption will be discussed further in Section 3.1.

Warehousing Costs. Items arriving at the IST incur holding costs each day until they depart on a ship for transport to Canada. Due to the unavailability of information on the the warehousing costs at the IST, the holding costs in the model were specified to be equal to those of comparable military warehouses in Canada. Holding costs at the Kandahar airfield were not considered.

2.4 Key Outputs

After the simulation has run to completion, several outputs are collected. These outputs include the route taken by each item to return to Canada, along with costs incurred, and timestamps along each section of the route. However, the main outputs of the model consist of the following four quantities:

Total Cost of the MTTF. This quantity consists of all costs incurred by the MTTF, and includes contracted costs of the AN-124 airlift, costs of the CC-177 airlift (operating costs, crew costs, and amortization costs of the equipment), costs of the contracted sealift from the IST, sea liner service costs from Karachi, holding costs for items at the IST, and costs of the contracted trucks used for transport of items for the GLOC.

Number of Flights Required. The total number of flights (AN-124 and CC-177) required to repatriate the items using the ALOC Direct and ALOC IST methods.

Completion of 50% of the Returns. The simulated time at which 50% of all items have been repatriated from Afghanistan using any of the various LOCs.

Completion of 95% of the Returns. The simulated time at which 95% of all items have been repatriated from Afghanistan using any of the various LOCs. *N.B.* the return date of the final item was not used as there were instances when vast majortity (in the order of 99%) of all items were repatriated by a given date, but a few items were delayed in their arrival to the IST and so had to wait for several months for another ship to depart for Canada. Considering the end date in such an instance would have unfairly skewed the results.

3 VALIDATION OF THE MODEL

In this section, the outputs of the simulation are compared to corresponding actual quantities in order to validate the model.

3.1 Aircraft Bulk and Payloads

The first set of quantities that are compared are the number of items on-board the aircraft flights (also referred to as the flight's *bulk*), and the payloads of these flights. All figures concerning the actual historical quantities were taken from the COP.

When comparing these quantities for the CC-177 aircraft, it was found that the mean simulated bulk (3.44 items) was comparable to the mean actual bulk (3.36 items). However, a Kolmogorov-Smirnov test (Massey, 1951) found that the null hypothesis that the datasets have the same distribution was rejected at the 95% confidence level. A similar result was found when the mean simulated payload (64,700 lb) was compared to the mean actual payload (71,500 lb). These distributions are presented graphically in Figure 2.

The difference in these distributions may be explained by the simulation using an unrefined method when selecting items to load on to the aircraft (in the order in which the items were received at the loading area), whereas in actuality experienced load masters carefully select items in order to maximize the load of the aircraft. Evidence for this conjecture comes from the fact that the average unused payload of the CC-177 aircraft was 4,100 lb in the simulation; and when this quantity was added to the simulated payloads, the null hypothesis was not rejected at the 95% level (with a *p*-value of 0.42).

The simulated and actual bulk and payload quantities were also compared for the AN-124 aircraft. The mean simulated bulk of the AN-124 (6.38 items) was comparable to its mean actual bulk (6.25 items), and in this case the Kolmogorov-Smirnov test did not reject the null hypothesis at the 95% confidence level (with a *p*-value of 0.27). Moreover, the Kolmogorov-Smirnov test did reject the null hypothesis at the 95% confidence level when comparing the payloads of the AN-124 aircraft (the mean simulated payload was 149,600 lb and the mean actual payload was 157,600 lb). These distributions are presented graphically in Figure 2.

The average unused payload of the AN-124 aircraft was 6,900 lb in the simulation. When this quantity was added to the simulated payloads, the null hypothesis that the simulated plus unused payload of the AN-124 and the actual payload datasets have the same distribution was not rejected at the 95% level (with a *p*-value of 0.12). Hence the difference in the payloads may be explained by the aircraft loading method, which can reduce the sizes of the unused payloads on the aircraft.

3.2 Repatriation as a Function of Time

One of the key measures used by the MTTF to estimate the progress made in the repatriation was the number of items (containers and vehicles) that had been returned to Canada as a function of time. One item listed in the MTTF COP is the number of items that had left the main Canadian base in Afghanistan (Kandahar Airfield) by week.

The actual number of items repatriated was compared to their corresponding simulated quantities. Both series can be found in Figure 2(e). The multiple series shown in the figure for the simulated quantities are due to the variance in the runs of the simulation.

Note that the number of items returned to Canada as a function of time in the simulation differs from the actual quantities by at most 12% until day 180 (approximately November 2011), when the series diverge substantially. This divergence corresponds to the date of creation of a holding yard off-base where items could be stored for eventual onward movement to Karachi via the GLOC (Department of National Defence (DND), 2011). Once created, items placed in the holding yard were considered off-base from a CF perspective, and were counted as such in the MTTF COP.

3.3 Number of Flights Required

Finally, the last point of validation concerned the number of flights needed to complete the ALOC portion of the repatriation. The number of flights (CC-177 and AN-124) needed in the simulation ranged from 333 to 370, with a median of 351. The actual number of flights needed was 357, which corresponds to the 75% quartile in the range found in the simulation. This information is presented graphically in Figure 2(f).

3.4 Validation Summary

Given that the simulation satisfactorily models reality to the extent that it can replicate the number of flights needed to return items from Afghanistan to Canada, at the correct rate, and subject to similar constraints on the load placed on each aircraft, the simulation is representative enough of reality to be an illustrative model for sensitivity analyses.

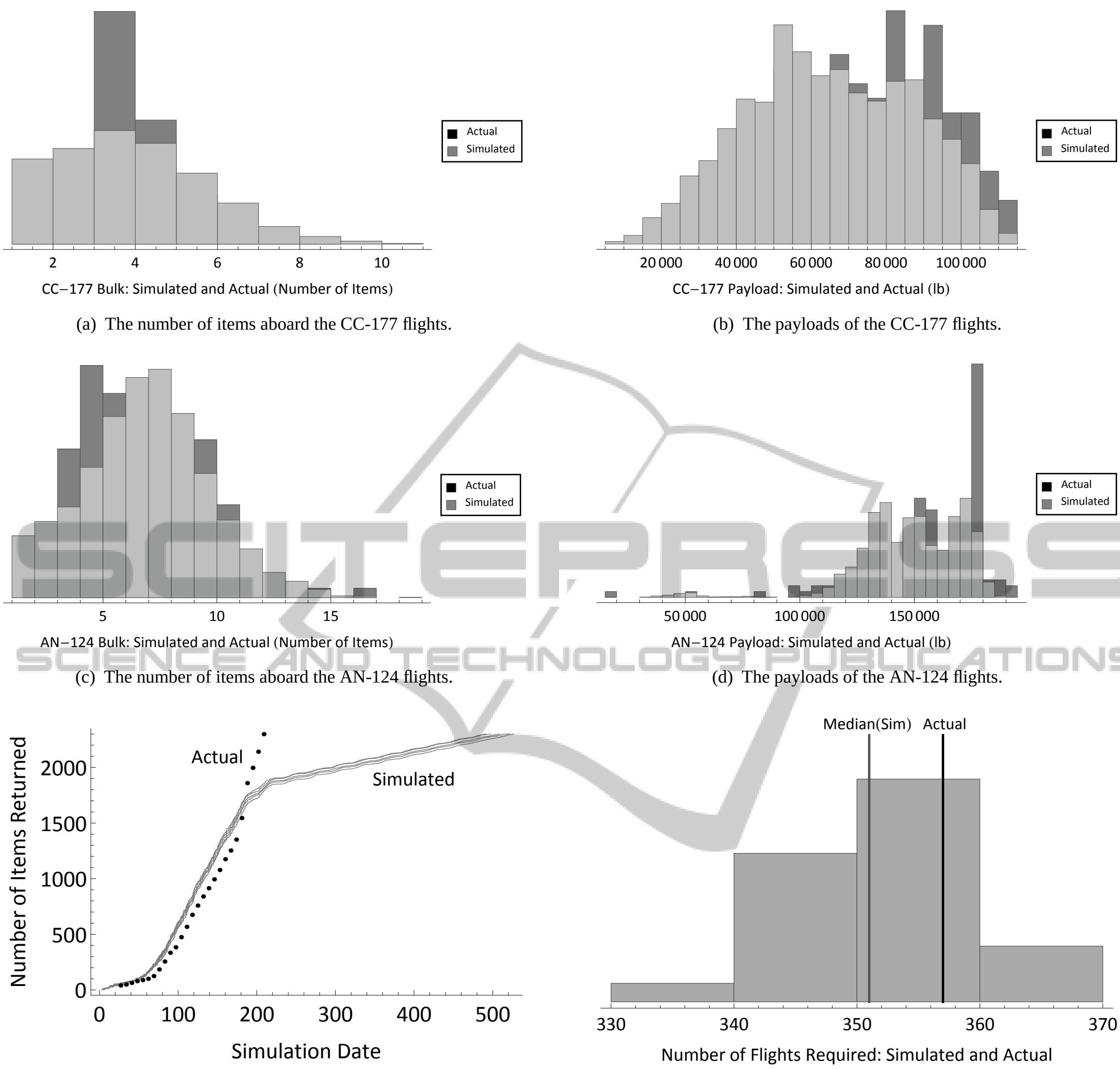
Up to this point in the paper the model has been used as a descriptive model of reality. In the next sections, the model is used to evaluate the impact of changes to physical or procedural aspects of the MTTF repatriation efforts.

4 RESULTS AND DISCUSSION

Several versions of the model were run with changes made to its various parameters to determine the impact of these changes on the four measures of performance of the MTTF (specified in Section 2.4: total cost, number of flights, 50% completion time, and 95% completion time). The unaltered version of the model is referred to below as the *baseline* model. The relative increases or decreases of the outputs over the baseline are specified in this section.

The analyses performed were fivefold - wherein one (and only one) of the following things were varied, with all else remaining constant:

1. Increases to the number of items returning by ALOC Direct, with proportional removal from one of the other two methods.
2. Decreases to the number of items returning from GLOC, with increases going to the number returning by ALOC IST;



(a) The number of items aboard the CC-177 flights.

(b) The payloads of the CC-177 flights.

(c) The number of items aboard the AN-124 flights.

(d) The payloads of the AN-124 flights.

(e) The number of items returned to Canada as a function of time (in days). Note that Day 1 corresponds to May 1, 2011.

(f) The total number of CC-177 and AN-124 flights required.

Figure 2: Comparison of several actual and simulated quantities. Subfigures 2(a) to 2(d) illustrate the bulk and payloads of the CC-177 and AN-124 flights departing Afghanistan in support of the MTTF. Subfigure 2(e) presents the number of items returned to Canada as a function of time; and Subfigure 2(f) presents the total number of flights required for the ALOCs.

3. Ordering of the types of aircraft used – selecting the AN-124s ahead of the CC-177s if both were available, or random assignment to either type of aircraft (the baseline assumes loading of the CC-177s first if they are both available);
4. Delaying the first scheduled departure of all flights (ALOC Direct, and ALOC IST) by several months (30, 60, 90, or 120 days) to take advantage of the lower temperatures in the later months; and
5. Increases to the availability of the different aircraft (AN-124s and CC-177s), *i.e.*, the number of aircraft of each type available for use in the ALOCs each day.

The results of each of these changes is discussed in sequence in the following subsections.

4.1 Increases to ALOC Direct

It was hypothesized that increasing the number of items transported via ALOC Direct would decrease the total time to complete the total return but would increase the total costs (due to increases in the number of flights required). The analysis found that this hypothesis was correct: increasing the number of items returning by ALOC Direct, and correspondingly decreasing the number of items returning via one of the other two methods (ALOC IST or GLOC), would have had the effect of increasing costs while decreasing the total time to complete the total return by approximately equal amounts.

More specifically, doubling the number of items returning by ALOC Direct would have had the effect of increasing the total cost by 10% while decreasing the time to complete 95% of the repatriation by 7%. If instead the number of items returning by ALOC Direct was increased fourfold, the total cost would have increased by 28% and the time to complete 95% of the repatriation would have decreased by 22%. The results for this modification are presented in Figure 3(a).

4.2 Decreases to GLOC

Another possibility for speeding up the repatriation was a reduction in the number of items requiring transport by GLOC, which was thought to be the slowest of all options. It was found that decreasing the number of items returning by GLOC (and subsequent movement by SLOC) would have had the effect of increasing costs and the number of flights required, and has a marginal effect on the time to complete half the returns. However, it would have had a substantial effect on the time to complete 95% of the return of the items. This result is due to the fact that the the airlift portion of the repatriation is done much earlier than the sealift portion; hence, hastening the sealift portion of the returns has a large impact on the time required for the total return.

More specifically, decreasing the number of items returning by GLOC by 67% of its original value would have had the effect of increasing the total cost by 14%, increasing the number of flights by 18%, and decreasing the time to complete 50% of the returns by 3%. However, the time to complete 95% of the repatriation would have decreased by 47%. The results for this modification are presented in Figure 3(b).

4.3 Ordering of the Aircraft

AN-124 aircraft are contracted airlift vehicles, and are thus more expensive than the CC-177 fleet which is native to the CF. It was suspected that if more items travelled by CC-177 instead of AN-124, costs incurred by the MTTF could be reduced.

However, it was found that changing the ordering of the aircraft for loading and departing for the ALOC (Direct or IST) would have had a negligible effect on all outputs studied. None of the outputs would have varied by more than 1% by selecting the AN-124s ahead of the CC-177s if both were available as opposed to the baseline case of selecting the CC-177s first. A similar result was found for the case of randomly selecting either type of aircraft instead of always selecting the CC-177s first. The results for this modification are presented in Figure 3(c).

4.4 Delaying the Aircraft Departures

Recall that the external air temperature has a large effect on the maximum allowable payload for both the AN-124 and CC-177 aircraft. It was hypothesized that by delaying the first scheduled departure of all flights (for ALOC Direct as well as ALOC IST) by several months (30, 60, 90, or 120 days), one could take advantage of the lower temperatures in the later months, potentially reducing the flights required.

It was found that that these delays would have had a small effect on total costs (up to a 5% savings), but the time needed to complete half the returns was increased by substantial amounts (up to 38%). However, the time to complete 95% of the returns would have been unchanged due to the final items always awaiting a ship for sealift via the SLOC. The results for this modification are presented in Figure 3(d).

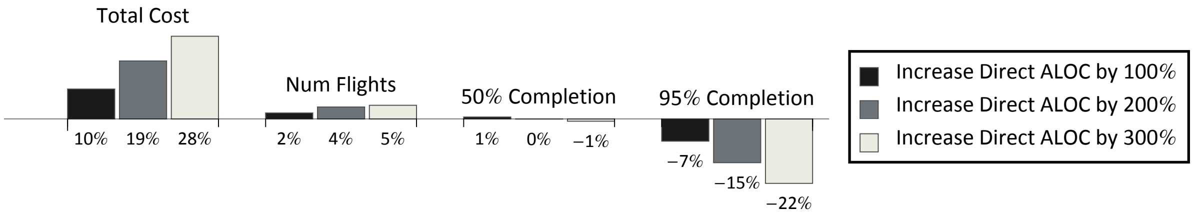
4.5 Increasing Aircraft Availability

It was hypothesized that if there were more aircraft (CC-177s and AN-124s) available to the MTTF, the repatriation of the items may have progressed at a faster rate. This analysis tested that hypothesis, by increasing the number of aircraft available for ALOC purposes by 33%, 66%, or 100%.

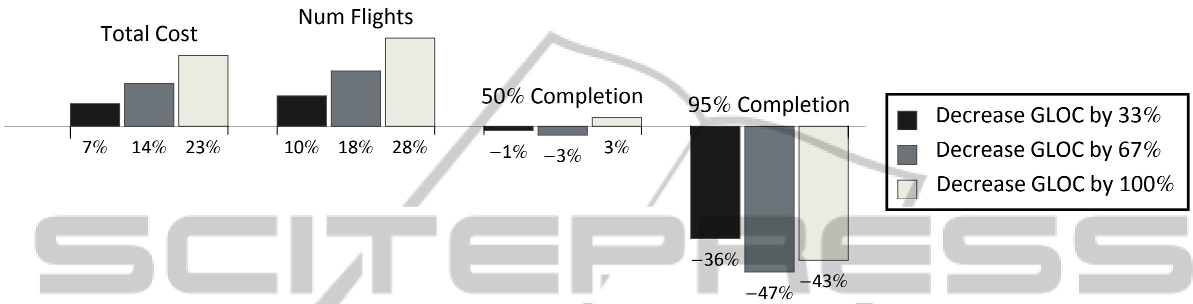
It was found that increasing the availability of the aircraft would have increased the cost and total flights by small amounts (up to 4% and 6%, respectively), but the time to complete 50% of the returns would have been dramatically reduced - by up to 35%. Again, the time to complete 95% of the returns would have been unchanged due to the dates of the sealift portion of the returns. The results for this modification are presented in Figure 3(e).

5 CONCLUSIONS AND RECOMMENDATIONS

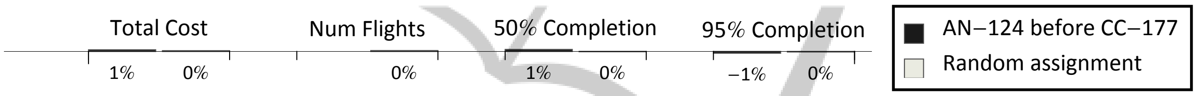
The objective of this study was to develop a model that could be used to analyze the repatriation of Canadian equipment from Afghanistan to Canada via the LOCs, in order to enable and improve future mission planning.



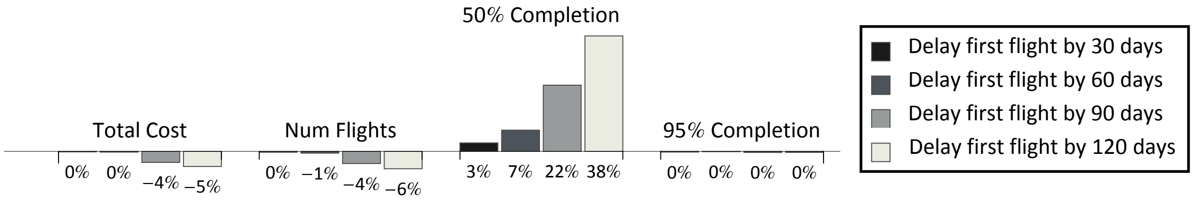
(a) Effects of increasing the number of items returning by ALOC Direct, and correspondingly decreasing the number of items returning via one of the other two methods (ALOC IST or GLOC).



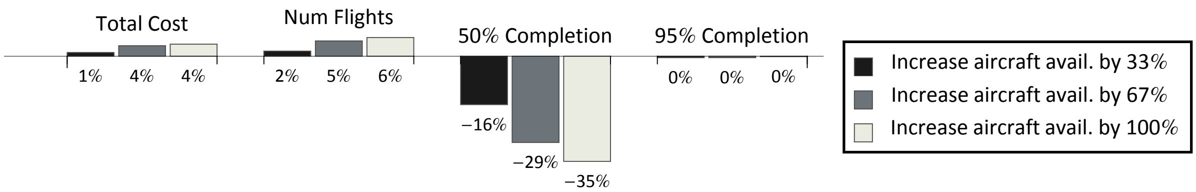
(b) Effects of decreasing the number of items returning by GLOC, and correspondingly increasing the number of items returning via ALOC IST.



(c) Effects of altering the ordering in which the aircraft were selected – selecting the AN-124s ahead of the CC-177s if they were both available, or random assignment to either type of aircraft (the baseline assumes loading of the CC-177s first if they are both available).



(d) Effects of delaying the first scheduled departure of all flights (ALOC Direct, and ALOC IST) by several months (30, 60, 90, or 120 days) to potentially take advantage of the lower temperatures in the later months.



(e) Effects of increasing the availability of the different aircraft (AN-124s and CC-177s) for use in the ALOC.

Figure 3: The results of specific changes to the model's parameters are shown in each of the subfigures. The relative changes of each of the key outputs (total cost of the MTTF, the number of flights required, completion of 50% of the materiel returns, and completion of 95% of the materiel returns) are illustrated as relative increases or decreases to the baseline value found in the unchanged version of the model.

A discrete-event simulation model was developed and shown to be representative of actual the repatriation of items from Afghanistan. The model was then used to determine the impacts of different potential courses action, measured mainly through results on the total cost and duration of the returns.

Results indicate that increases to the number of items using the ALOC Direct method of shipment would have both increased total cost and decreased the time to complete the repatriation. Decreasing the number of items returning by GLOC would have increased cost to a moderate extent while significantly decreasing the time to complete the repatriation. Delaying the departure of the flights to the cooler months would have decreased the total costs as well as the number of flights required of the aircraft while having no effect on the time to complete the repatriation. Finally, increasing the availability of the aircraft would have increased the cost and the number of flights while having no effect on the time to complete the repatriation.

There is a subtle and complex relationship between the parameters of the model and its main outputs (the total cost incurred and the time to complete the repatriation) that is due to the scheduling of the returns via airlift and sealift, as well as the overall per-container cost for each different method of shipment. This type of model can provide insights into the factors affecting these outputs – insights which would perhaps otherwise go unnoted. It is recommended that in future operations a model similar to one detailed here be constructed to investigate how the repatriation could be optimized prior to the initial departures and during mission execution. More specifically, this model can be used in the repatriation of the materiel from Operation ATTENTION, which is expected to conclude in 2014.

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