Modeling Maritime Combat Logistics in a Theater Warfighting Campaign

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ABSTRACT

In response to challenges posed by a return to strategic global competition, Navy and Marine Corps developed Distributed Maritime Operations (DMO) and Expeditionary Advanced Base Operations (EABO) concepts for conducting far forward combat operations in contested environments. Combat operations and the effectiveness of different combat capabilities has often been the measure of effectiveness in campaign analysis. An in depth examination of the interdependence of the combat force and the ability to sustain the logistics force has been lacking in previous campaign analysis. Systems Planning and Analysis (SPA) developed a logistics force level model accounting for refuel, resupply, and rearming of maritime combat forces supporting these concepts in a future-year, campaign-level, Pacific theatre warfighting scenario. In order to capturing afloat logistics requirements necessary to meet a theatre level wartime scenario - from the warehouse to the front line - SPA developed a nodal analysis for fuel, supplies, ordnance, rescue, and repair demand across the force using a theatre-level warfighting campaign scenario. This broader treatment of operational logistics was applied to future force level analysis in SPA's stochastic General Campaign Analysis Model (GCAM) to showed changes in campaign-level combat produced by Navy ships as a function of the degree of interruption of the logistics flow relative to enemy attacks on logistics units.

Keywords: Afloat logistics, Campaign analysis, Combat operations, Contested environments. Distributed Maritime Operations (DMO), Expeditionary Advanced Base Operations (EABO), Operational logistics.

1.0 INTRODUCTION

Admiral Hyman Rickover, United States Navy (USN), stated "Bitter experience in war has taught the maxim that the art of war is the art of the logistically feasible." Without taking logistics into account in campaign level modeling, the feasibility of the Concept of Operations (CONOPS) being examined cannot be properly assessed. Most campaign models look at capability and capacity of the combat forces but do not properly assess the logistics requirement needed to keep those front-line forces adequately supplied and able to perform their missions. Modeling logistics is often overlooked because establishing a logistics network requires a level of understanding of both the logistics demand of the customers (front-line forces) as well as the capability and capacity of the provider (logistics ships). Overlooking logistics could lead to an unrealistically low force structure requirement as the combat forces required to protect the logistics are unaccounted for or presume an unrealistically high force laydown and composition unable to be supported by the available logistics force. Understanding all the interdependencies between the demand of the operational forces against the capability and capacity of the logistics force, as well as the level of risk based on the operational scenario, is important to establishing a logistics force architecture that can support combat operations. This paper attempts to describe some of these interdependencies and how they were modelled in a scenario spanning months of operations.

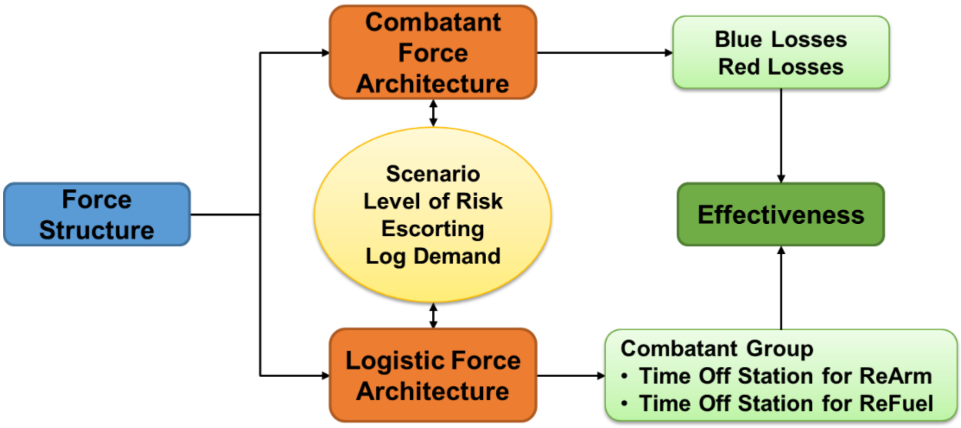

Figure 1: Combat force architecture.

In the Next Generation Logistics Ship (NGLS) analysis both the warfighter and logistician were brought together to determine the manner in which Distributed Maritime Operations (DMO) [1] and Expeditionary Advanced Base Operations (EABO) [2] concepts would be conducted, the anticipated inflection points of that conflict, and the laydown and movement of those forces. Once the broad strokes of the campaign were established, the logistics architecture was established based on locations and the consumption rates of the forces. A feedback loop then determined if the initial laydown and movement could be supported by the logistics as well as the combatant forces available. The measure of performance used by the model was whether or not the front-line combatant forces were fully supported by the logistics forces in a non-combative environment. Once a working model, where all combatants were sufficiently sustained, was achieved then interaction between red and blue forces was introduced to determine the effectiveness of the entire concept of operations.

2.0 VARIABLES IN MODELLING LOGISTICS

When modeling logistics, one has to realize that logistics is essentially nodal analysis. To determine the logistics requirements, the total demand across the force needed to be calculated based on the composition and laydown of the force. There were multiple factors used in determining the logistics force required:

- Composition of each group of forward forces.
- Daily usage rates of the commodities being examined.
- Transit speed and capacity of the logistics forces.
- Commodity transfer rates of the logistics forces.
- Commodity safety level of the combatant forces for each commodity.
- Distances from the rear resupply areas to the forward resupply areas.
- Distances from the forward resupply areas to the forward forces.

Note that the capacity of land based resupply areas was not taken into account since the model was examining the afloat forces.

One of the most difficult aspects of modeling logistics is determining the daily usage rates of the forces for the 2045 timeframe which includes future, unrealized platforms. As with all campaign models, the right level of fidelity versus the ability to run a campaign model over a time span of several months needed to be balanced so that model run times were not prohibitively long. For supplies, non-Vertical Launching System

(VLS) ordnance, and the fuel usage rates for non-combatant forces from the U.S. Navy planning guide, Naval Weapons Publication (NWP) 4-01.2 [3], was used to simplify the modeling. Because fuel was the driver for most of the combatant forces, a more explicit planning factor was required. Diesel Fuel Marine (DFM) usage rates were derived from the anticipated fuel burn curves of combatants provided from Naval Sea Systems Command (NAVSEA) [4]. The actual usage rates for VLS ordnance were used based on the threat and concept of operations in this campaign model.

To determine the required number of logistics forces to support the combatant force, SPA developed a deterministic model that examined the **turnaround time** of the logistics forces to service the customer and the **revisit rate** required by the customer to determine the number of logistics forces required to support the CONOPS.

Turnaround time is a function of the speed of the logistics ship, the distance to the resupply transfer point, and the transfer times of the commodities. The revisit rate is a function of the storage capacity of the customer, the usage rate of the customer, the capacity of logistics ship, and the minimum level of a commodity before returning to a port to replenish that commodity (or commodity safety level). Figure 2 is a depiction of the balance between Turnaround Time and Revisit Rate.

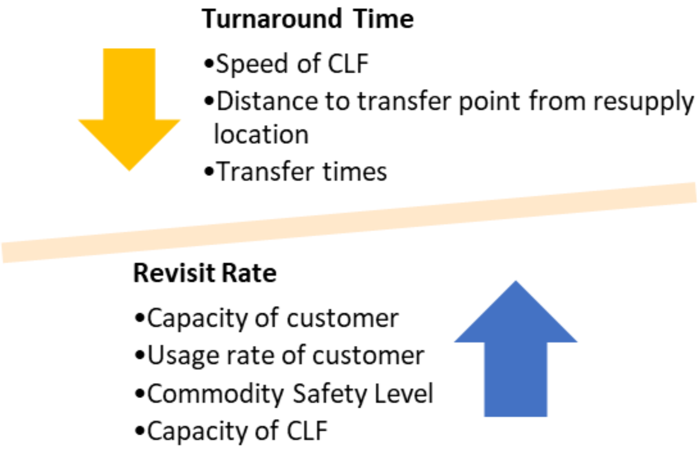

Figure 2: Deterministic logistics model.

Several things needed to be taken into account when modeling logistics, including that the inherent friction that occurs in the real world is not in a deterministic model, the need to minimize the combatant forces when protecting logistics forces, and how the movement of the combatant forces affect the logistics force.

The deterministic model that SPA developed for logistics force scheduling did not take into account friction points such as queuing at high demand, low density resupply hubs or the variability in usage rates that would occur in the real world that a stochastic model attempts to recreate. To take into account for this friction, SPA developed another model to schedule logistics forces to meet the revisit rate based on the turnaround time of the logistics force. The output of this model is the interval between logistics forces servicing a resupply hub. Additionally, the number of combatant forces used to support the protection of logistics forces is limited; therefore, logistics forces were paired when appropriate to minimise number of escorts.

Most examples of resupplying forward forces are periodic resupply events. Periodic resupply occurs when the customer stays in a relatively fixed location and the logistics forces provide services on a predictable schedule. However, there are times when the logistics forces and combatant forces meet at a rendezvous location and then the logistic ship goes back to be resupplied and the combatants go to a forward area to conduct combat operations. In this episodic resupply event, the customer fuel safety threshold level determines the logistics force scheduling since the combatant is returning to the rendezvous area at the minimal fuel level. This type of resupply method tries to minimise the level of risk to the logistics force as well as extend the operational reach of the combatant force.

The SPA models generate pairing and scheduling schemes to minimise the number of logistics forces and the corresponding number of escorts to support the CONOPS without having to return to rear resupply location.

3.0 CHALLENGES TO MODELING LOGISTICS

3.1 Modeling Phases of Operations

One of the most difficult aspects of modeling logistics was accounting for different phases of operations. In most campaign models, there are phases of operations were the location and composition of combatant forces changes between phases. In this model, each phase of operation had to be treated as a separate logistics architecture.

During the transition between phases, modeling showed that logistic forces drove the success of whether the transition from one phase to the next was successful. In early development of a logistically feasible campaign model, the combatant forces were allowed to move from one phase of operation without regard to the status of the logistics force. This proved unsuccessful because the combatant forces quickly outran their logistics support and then had to return to the rear resupply hubs since they would hit their commodity safety threshold level.

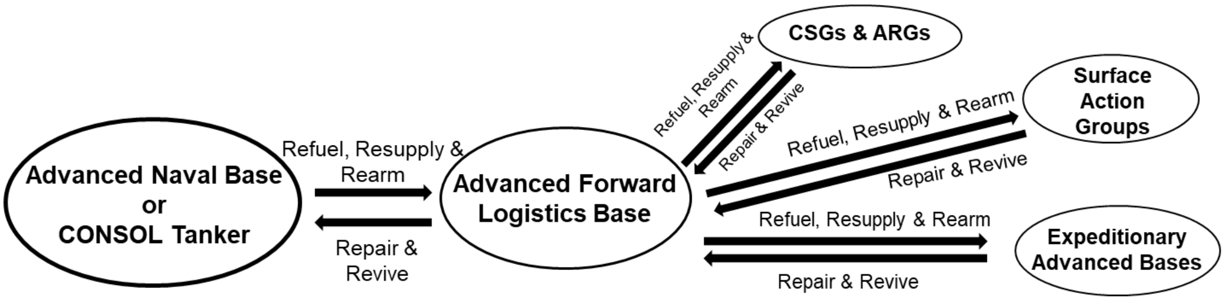

Figure 3: Flow of logistics.

The key to successfully transitioning from one phase of operation to another was to ensure that each level of logistics was in place before transition to the next phase. For example, the logistics forces that serviced the Advanced Forward Logistics Base (AFLB) from the Advanced Naval Base (ANB) or CONSOL tanker location in Phase I would have to arrive at the new AFLB location for Phase II before the combatant forces could move to their new locations in Phase II to ensure that the logistics lines were never overextended.

3.2 Reducing Queueing Issues

As alluded to earlier, friction was not accounted for in the deterministic logistics planning models but can prove to be a major problem in modeling when simulating a military campaign over months of conflict. The biggest friction point for logistics modeling is the queue that can form when you have a high demand low density node of an AFLB, which is a point in open ocean where the larger logistics ships, T-AO (Oiler), and T-AKE (Solid cargo, Ammunition) arrive to service customers, then disperse. Because they are the central point of all refueling operations the employment of the T-AOs is key to making the logistics architecture succeed.

T-AOs perform as a shuttle oiler and a station oiler. A shuttle T-AO goes from the rear fueling area to the station oiler, swaps roles with the station oiler, who then returns to the rear area to be refueled in the shuttle role. A station T-AO is station oiler for either a Carrier Strike Group (CSG) or Expeditionary Strike Group (ESG) and are the resupply location for the NGLS. Once resupplied the NGLS goes forward to the Surface Action Groups (SAGs) or Marine Littoral Regiments (MLRs) that are in forward operating positions.

A CSG is comprised of an aircraft carrier and multiple cruiser destroyer (CRUDES) escorts to protect the aircraft carrier. An ESG is comprised of multiple amphibious ships and multiple CRUDES escorts to protect the amphibious ships. The aircraft carrier requires aviation fuel for the aircraft but no diesel fuel since it is nuclear powered. The amphibious and CRUDES ships require diesel fuel for their engines as well as aviation fuel for the aircraft embarked on the ships. The station T-AO servicing the CSGs and ESGs are only able to refuel two ships at once and have a limited work day. A CRUDES ship takes approximately two hours to complete a refuel/resupply evolution.

To alleviate T-AO queueing such techniques as the overall employment of the ESGs, and the prioritization of the NGLS over all other users was examined. Delaying the NGLS at the T-AO could result in a delay in resupplying the SAGs and MLRs in the forward operating areas. Since there was little excess capacity in the logistics architecture, any delay in the NGLS returning to resupply the forward units could result in those units coming off station and returning to the nearest refuel/resupply depot. A buffer of 12 hours was used in the model to reduce queuing. When the NGLS was 12 hours from the station T-AO the T-AO would stop servicing other customers to ensure that the NGLS was able to refuel and resupply without delay. As other aspects of the logistics model were improved the 12 hour service delay was reduced to 4 hours.

There are a finite number of T-AOs, minimising the number needed is key to the success of the logistics architecture. The amphibious ships in the ESGs are able to go for extended periods of time without having to refuel but when they do refuel, they require a large amount of fuel. To reduce the number of T-AOs in the architecture the employment of the ESGs were optimized to reduce the amphibious ship demand from the T-AOs. To alleviate the need for amphibious ships to refuel from the T-AO, ESGs were rotated from forward operating stations to forward resupply bases in order to reconstitute the amphibious force. The frequency of reconstitution was such that one T-AO was sufficient for each ESG. The one T-AO assigned to the ESG supported the CRUDES escorts, since their refueling frequency was greater than the amphibious ships.

3.3 Modeling Real World Movements

Fuel usage for the CRUDES escorts was explicitly modelled in this analysis. The type of operation, such as transiting between operating areas or patrolling an operating area, determined the hourly diesel fuel usage rate. The main driver for diesel fuel usage for the SAGs was the transit speed between operating areas. Initially, transit speeds of 22-26 kts was used but this resulted in the SAG having very little time on station at the forward operating station. To alleviate this problem either the transit speed could be reduced, or the forward operating area could be brought in closer. Note that the speeds, distances, and times on station are notional for purposes of this discussion.

SAGs in this study are a mixed composition of ships; therefore, the fuel efficiency of the entire group must be determined to find the best trade-off for the transit speed of the SAG to travel to the forward station. Since the vessels all have different speeds at which they travel efficiently and after exceeding it, burn fuel in an inefficient manner, the study must answer the question, “What is the right speed for the SAG to travel that would maximize its time at the forward operating station based on the distance from logistics support”?

As shown in Table 1 below, considering a 70% DFM fuel safety factor as the limiting factor, a mixed SAG’s optimum distance from its refueling point is approximately 800 nm. Although it does not have as long a time on station as the 700 nm row, it allows for the SAGs to close the threat by another 100 nm at the cost of only about half a day on station.

Table 1: Time on Station with a Fuel Safety Factor of 70%.

Time on Station (Days) for Mixed SAG (70% Fuel Safety Factor)						
		SAG Transit Speed to Station (kts)				
Distance from Refueling Point (nm)		18	20	22	24	26
	700	3.04	3.11	3.10	3.02	1.70
	800	2.54	2.62	2.62	2.42	0.05
	900	2.04	2.14	2.13	1.24	Too Far
	1000	1.53	1.65	1.40	0.06	Too Far
	1100	1.03	1.17	0.65	Too Far	Too Far

In consultation with the study leadership, it was determined that the SAGs needed to sail beyond the 800 nm. However, increasing distance from the refueling point would significantly limit the number of days at the forward operating station. In the case of the upper speed of 26 kts, it is not feasible to get to the 900 nm range. This analysis examined ways to mitigate the limited time forward conducting sea control operations.

There are two factors that can be manipulated to increase the SAG time on station and/or distance from logistical support. The first factor is to reduce the SAG transit speed. As evidenced by Table 1 above, fuel efficiency is reduced above 22 kts and significantly reduced above 24 kts. The decision was made to reduce transit speeds from 22-26 kts to between 20 and 24 kts.

The second factor is the fuel safety factor. Let us assume that the fuel safety percentage is 70%. By reducing the fuel safety factor from 70% to 50%, time at the forward operation station and/or distance from logistical support could be increased. The downside of this reduction in the fuel safety factor is to accept an increased risk of running out of fuel if there is a break down in the sustainment loop.

Table 2 below shows the added time the SAG can remain on station by changing the fuel safety factor from 70% to 50%. By reducing the fuel safety factor, the increase in time operating at a forward location 1100 nm from logistics support increases from 1.17 days to 3.57 days at 18 kts and at a transit speed of 26 kts on station time increases from an infeasible (-1.12 days) to 2.85 days. By reducing the SAG transit speed to between 20 and 24 kts and adjusted SAG fuel safety factor to 50% provides 3.49 days to 3.59 days on station at a forward location 1100 nm from the refueling point. These assumptions were used in the model to strike the balance between the risk of running out of fuel against the need to have forces in a forward operating area.

Table 2: Fuel Safety Factor of 50%.

Time on Station (Days) – SAG Operating 1100 nm from Refueling Point						
		SAG Transit Speed to Station (kts)				
SAG Fuel Safety Factor (%)		18	20	22	24	26
	0.7	**1.17**	**1.19**	**0.65**	Too Far	Too Far
	0.65	1.77	1.79	1.45	0.96	Too Far
	0.6	2.37	2.39	2.24	1.95	0.86
	0.55	2.97	2.99	2.96	2.89	1.86
	0.5	**3.57**	**3.59**	**3.56**	**3.49**	**2.85**

4.0 DETERMINING LOGISTIC FEASIBILITY

It is easy to state that a model is logistically feasible, but it is rather difficult to ensure that is in fact, logistically feasible. In troubleshooting the model, it was necessary for us to determine all the various states that a group could be in. The states that we used were as follows:

- On Station: At the operating location and performing the mission.
- Refueling: Returning to a refueling location due to hitting the safety factor for DFM or JP-5.
- Rearming: Returning to a rearming location due to hitting the safety factor for non-VLS ordnance.
- Resupplying: Returning to a resupply location due to hitting the safety factor for stores.
- Reloading: Returning to a reloading location due to hitting the safety factor for VLS cells.
- Standby: At a location waiting for another action to occur.
- Relocating: Transiting to and from an operating location.
- Dead: All ships in the group are attrited.
- Not in Theatre: Group had yet to arrive in the theatre.

Every group's state was recorded to determine if the CLF architecture was able to ensure that refueling, rearming, and resupplying events/states did not occur. Because the fog of war, we ran the model without red force interaction to ensure that there was no attrition to blue forces to ensure that the only variable was the effectiveness of the CLF architecture. Figure 4 below is the initial results of the model. Note that the SAG states are notional for purposes of this discussion.

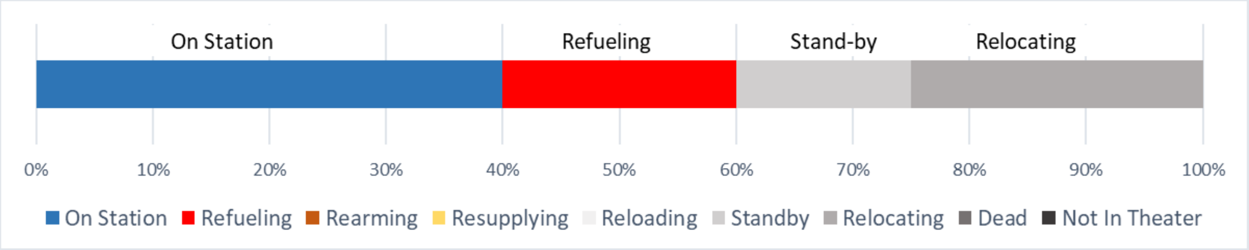

Figure 4: Initial surface action group state.

By making some of the changes mentioned previously, such as properly sequencing the order of events when transitioning from one phase of operation to another, reducing the queueing at the CLF ships, and ensuring that the speeds were operationally relevant so the combatant groups could get their operating locations in an expeditious manner without putting undue stress on the logistics architecture resulted in the following results for the SAG states. Figure 5 shows the model without attrition. Note that there are no refuel, resupply, or rearm events since the logistics architecture is stable and the CLF was able to provide those commodities while the SAG was forward.

The only time a SAG was off station was when transitioning from one event to another or while waiting to be serviced. This would ensure that once attrition was added any disruption to service would be because of Red concept of operations and not by an inadequate or brittle logistics architecture. Note that some of the states are greyed out. This signifies that those states are not affected by the performance of the logistics force. The performance of those states is driven by the underlying scenario concept of operations and scenario assumptions. As you can see by the notional SAG state in Figure 6, if the model was not logistically feasible it would have been difficult to determine if the refueling event was caused by attrition or by a logistic architecture that was not resilient to perturbations in the model.

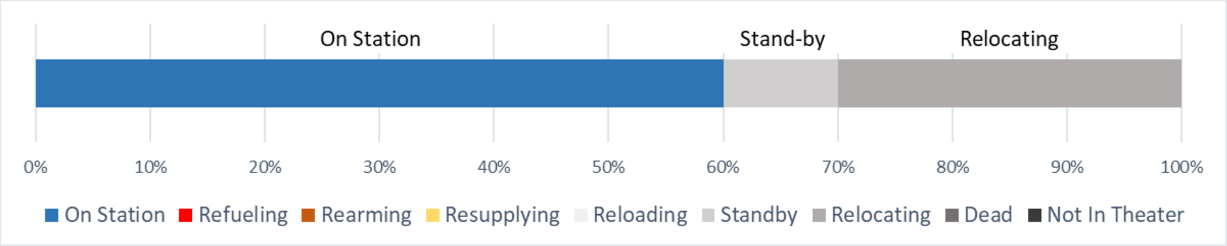

Figure 5: Notional surface action group state without attrition.

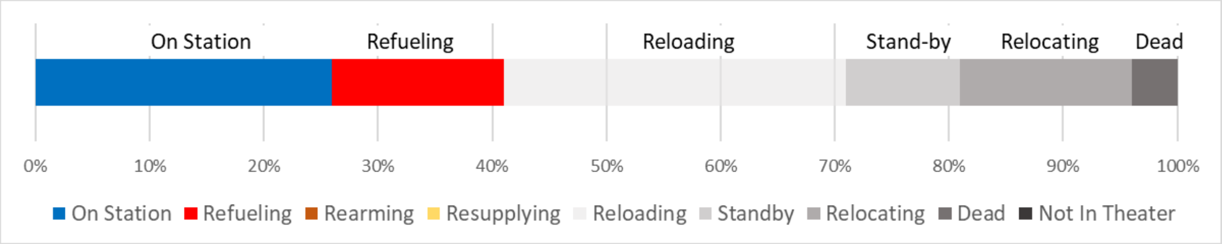

Figure 6: Notional surface action group state with attrition.

5.0 CONCLUSION

As Alfred Thayer Mahan once observed, “Logistics…as vital to military success as daily food is to daily work.” Most campaign analyses generally do not devote the proper effort towards ensuring the model accurately represents logistics. This can lead to unrealistic transit speeds, on- station times, and available forces to operate forward. Understanding all the interdependencies between the demand of the operational forces against the capability and capacity of the logistics force, as well as the level of risk based on the operational scenario, is important to establishing a logistics force architecture that can support combat operations. Failure to incorporate this level of fidelity into a campaign model will lead to unrealistic interchange between red and blue forces and therefore the effectiveness of the entire concept of operations will be difficult to access. This is a first attempt at understanding operational logistics afloat. The next steps are to build upon this work and better model the next level of the architecture as we work our way forward to last tactical mile and our way back to the first tactical mile.

6.0 REFERENCES

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