

## ABSTRACT

This paper presents a proof of concept for a Military Logistics Network Planning System (MLNPS) to be used during mission planning to quickly identify a robust logistical footprint that can adequately sustain units deployed in an expeditionary environment. The logistical network is modeled using an efficient form of goal-seeking deterministic discrete event simulation to process supply requisitions through the logistical network. The queuing information obtained from the simulation informs capacity adjustments to the network to maximize efficiency. This process of simulation and network tuning continues interactively until an adequate and robust logistical footprint is found. During the planning stages, the MLNPS can be used to identify and mitigate logistical problems instead of waiting to react to backlogs when the military's operations would have already been affected. Designed to run as an app on the Army's enterprise resource planning (ERP) system (Global Combat Support System-Army), the MLNPS can also be used during operations to inform commanders of expected operational impacts on logistics. Contingency operation scenarios are used to demonstrate the MLNPS' capabilities.

## INTRODUCTION

The US military supply network is the largest in the world (Parlier, 2011). The network consists of 24 wholesale supply locations and ~33,000 retail supply locations across ~86 countries. It uses ~10 different modes of transportation, receives ~50,000 daily requisitions, and manages ~2.4 million lines of inventory that total ~\$109 billion in inventory (Faris, 2014). Managing a network this large in an efficient and cost-effective manner requires enlightened management, the application of advanced analytics, and comprehensive planning. Historically, logistical planning for contingency operations has not embraced the size and complexity associated with the US military logistical network.

With the release of Defense Reform Initiative Directive #54 in 2000 (Deputy Secretary of Defense, 2000), logistic transformation plans focused on three themes: 1)

the need for automated decision-support tools, 2) the need for an end-to-end perspective, and 3) the need to leverage emerging technology. Deputy Secretary of Defense John J. Hamre stated that logistics efforts need to "leverage emerging technology to increase the visibility, accuracy, and speed of logistics operations without compromising our effectiveness" (Hodge, 2001, p. 2). The Joint Vision 2020 echoed similar themes; Chairman Joint Chiefs of Staff General Shelton mentioned the need for an "end-to-end set of information capabilities ... and enhanced decision-support tools that will improve analysis, planning, and anticipation of warfighter requirements" (Office of Chairman of the Joint Chiefs of Staff, 2000, pp. 9, 24). Logistical challenges encountered in 2003 during Operation Iraqi Freedom (OIF) reinforced the need for logistical improvements. A 2005 study by the RAND Corporation on the logistical operations of OIF found significant logistical deficiencies due in part to a lack of theater distribution planning and decision-support tools. Motivated by significant readiness degradation to the US Army's 3rd Infantry Division during the invasion of Iraq, the authors recommended that "planning tools and organizational structures need to better support expeditionary operations" with "effective automation to rapidly determine capability requirements" (Peltz et al., 2005). Our model seeks to answer that call to action.

In July 2005, the United States Army began an "IT Solution" project designed to replace more than 200 standalone and redundant legacy logistical systems with one fully integrated modern logistical system. This new database system is comprised of three different enterprise resource planning (ERP) tools and is powered by the commercial-off-the-shelf enterprise software system, SAP® (www.sap.com). Together, these three confederated ERPs make up a web-based end-to-end system that allows the Army to see and share supply chain information in real time. One of these is the Army's tactical ERP system, known as the Global Combat Support System-Army (GCSS-Army, <http://gcss.army.mil/>) (Parlier, 2016). To our knowledge, no current logistical planning or decision-support tool harnesses the data stored in GCSS-Army. With GCSS-Army, it is possible to create an automated planning tool to rapidly determine end-to-end

# A Military Logistics Network Planning System

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*APPLICATION AREAS:*  
Resources-Logistics,  
Joint Warfare,  
Expeditionary Warfare  
*OR METHODS:*  
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logistical capabilities requirements for the US Army.

This article presents a prototype for a tool that uses advanced analytics and mission-based forecasting (Parlier, 2011), an emerging methodology for predicting military repair part demand, that helps predict choke points in an existing logistical network and provides valuable information about how to eliminate those choke points. The proposed tool uses a rapid, repetitive, goal-seeking simulation to model the routing of all requested supplies from receipt of the requisition to delivery of the supplies to the customer. It routes the supplies along the available transportation modes subject to the available transportation assets, while satisfying the customer by minimizing the maximum lateness of all requisitions. When simulating the movement of all requisitions across the entire network, queuing occurs at logistic nodes. The identification of queuing along specific transportation routes signifies potential choke points that may arise due to daily logistical requirements or, most likely, by the increased demands from global deployments and other mission sets. Once potential choke points are identified, the decision-support tool allows the decision maker to shift or add transportation assets, or other logistical capabilities, to reduce or even eliminate these choke points. The tool can then run with the revised logistical network and once again determine potential choke points. This process can be repeated in real time until the logistical network can sustain all operational missions or the decision maker determines that an operational mission or planned mission must be adjusted.

With the advanced analytics running the model and mission-based forecasting to help improve the model's predictive capability, this decision-support tool can be used in several ways. The model can be run on a daily basis to help keep the Army's logistical network running in an efficient and cost-wise manner. It can be used as needed to determine the impact of potential disruptions such as weather and enemy actions on the network. The tool can also predict the logistical impacts of operational plans during contingency planning. This allows Army senior leaders and planners to have logistical contingency plans "on the shelf." Lastly,

the tool allows senior leaders and planners to have a proof of concept tool during crisis action planning. The tool allows them to plan the logistics of a mission as quickly as they can conduct the operational planning to see if the operational plan is logistically feasible. The speed of the tool actually permits them to plan the logistics faster than operational planning and present logistical impacts of different size missions during mission analysis.

Although a few specific functions of the proposed decision-support tool have been discussed, the possibilities go far beyond just those few. The tool can be adapted to meet other logistical requirements that can further improve Army supply chain management to include manning requirements over time at national distribution points (shown later in this paper). These adaptations can readily include reverse logistics as well as other classes of supply to include the fuel network. Of particular interest is rapidly assessing the impact of disruptions and the required capacities of the logistical network to support expeditionary operations as these assessments are often required to be done in a time-constrained environment and inform senior leader decisions related to US national security strategic options.

This paper presents a novel approach to estimating logistical plan performance, identifying a feasible and acceptable capacity plan, and performing "what if" analysis to assess impacts of disruptions to the distribution network or other potential scenarios. Model validation uses logistical data from the 2003 invasion of Iraq to apply this method to the OIF planning scenario to demonstrate model functionality. Then, using a notional operational scenario set in Africa, we demonstrate how to use the tool to plan a logistical network and assess operational impacts of possible disruptions. The intent is to equip military logistics planners or analysts with a tool that can support rapid logistics analysis and is capable of using GCSS-Army data.

## LITERATURE REVIEW

The basis of the advanced analytics needed to solve the problem at hand is akin to what is

needed to optimize the flow of jobs with due dates through a factory. The Army logistical network can be thought of as one huge factory where parts/requisitions (jobs) need to be routed through different logistical nodes (machines) to reach their final destination (complete the job) by the established due date. There is extensive literature on the routing of parts in a factory to solve many different optimization problems. Most of the literature, however, does not address problems of the same scope and size as the Army logistical network. Few of the solution techniques in the literature can solve such a problem or can come up with a good solution within any reasonable amount of time. One advanced analytics tool that can find good solutions to very large scheduling problems in a short period of time is the Virtual Factory (Hodgson et al., 1998). The authors used revised slack and a repetitive deterministic simulation-based procedure to solve the N-job, M-machine, large job shop scheduling problem for minimizing maximum lateness ( $L_{max}$ ) – the N/M/ $L_{max}$  problem—which is known to be NP-hard (Garey, et al., 1976). We introduce the Virtual Factory as applied to our logistical problem. Starting from the present state of the system (i.e., the location of every requisition in the system plus its residual routing), the Virtual Factory runs a simulation. Requisitions are sequenced at logistical nodes in order of increasing slack (the maximum time a requisition can be in a queue at a node and still meet its due date for the ordering unit). Let  $d_i$  be the due date of requisition  $i$  and  $p_{ij}$  the processing time of requisition  $i$  at logistical node  $j$ . The slack of requisition  $i$  at node  $m$  is then defined as

$$slack_{im} = d_i - \sum_{j \in m+} p_{ij},$$

where  $m+$  is the set of all operations along the route of requisition  $i$  that are performed after completion of the requisition on node  $m$ . Since using slack to sequence a requisition does not account for potential queuing, revised slack (time at which a requisition needs to begin processing at the node to meet its due date) is used after the first iteration to provide better results. Queuing times from the deterministic

simulation are recorded for each requisition at each node and then revised slack is calculated by incorporating the queuing times. Let  $q_{ij}$  be the queuing time for requisition  $i$  at node  $j$ . Revised slack is defined as

$$slack'_{im} = d_i - \sum_{j \in m+} p_{ij} - \sum_{j \in m++} q_{ij},$$

where  $m++$  is the set of all operations along the route of requisition  $i$  that are performed after completion of the requisition at node  $m$  except the one immediately following  $m$ . The simulation is then run with requisitions sequenced at each node in order of increasing revised slack. This process is repeated, using continually updated revised slack, until an iteration limit is reached or the lower bound ( $LB$ ) on  $L_{max}$  is achieved. The Virtual Factory was originally tested using data from a large furniture manufacturing facility. The authors showed that the procedure achieved excellent solutions relative to the  $LB$  on  $L_{max}$  in little computational time. They found that problems tend to stabilize at an excellent  $L_{max}$  after 10 or less iterations of the simulation.

To represent the external transportation required to run multifactory manufacturing supply chains, Thoney et al. (2002) introduced the use of batch processors in the Virtual Factory. Batch processors are machines that process multiple jobs at the same time and all jobs remain inside the batch processor until the operation is complete. This development permitted direct modeling of containers, trucks, cargo planes, and ocean freighters.

Although the Virtual Factory was initially created as an advanced analytics tool for solving large job shop scheduling problems, it can be used to solve other large problems that have a network similar to a factory. The first proposed use of the Virtual Factory to solve a military-related scheduling problem was the Deployment Scheduling Analysis Tool (DSAT), created to help plan for Army deployments to overseas countries (Trainor, 2001; Hodgson et al., 2004). DSAT schedules the movement of equipment from the unit's home station to the final staging area in the forward deployment location. Where DSAT focuses on building the time phase force deployment data needed to

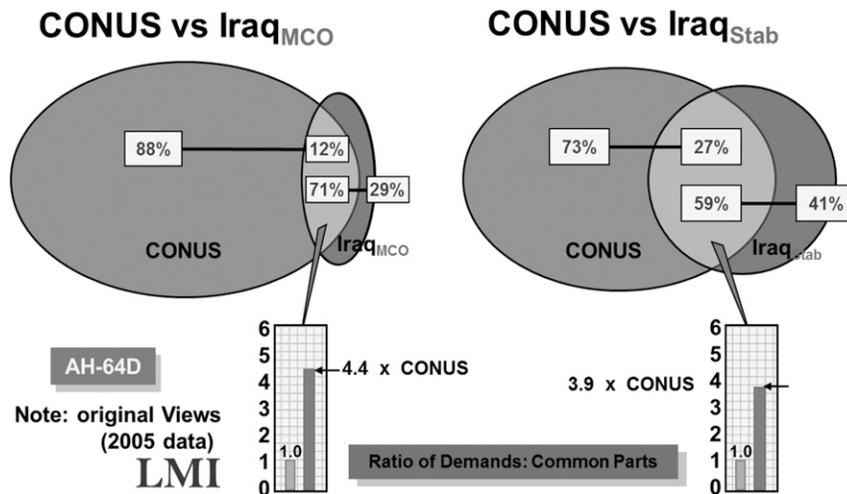
synchronize the movement of a unit from home station to theater, this paper focuses on the sustainment challenges of meeting the needs of units in an operational theater.

Forecasting is required to identify logistical problems in time to make effective interventions. The type of forecasting needed is mission-based forecasting. There is widespread literature on forecasting but very little literature on mission-based forecasting because it is a relatively new topic. Current Army forecasting techniques involve averaging past demand over several years and across many different mission sets and geographical locations (Parlier, 2016). The large variability in such average rates limits forecast accuracy for the multitude of different mission sets and potential operating environments faced by today's Army. The Army needs forecasts that are unique to a specific type of unit, conducting a specific type of mission, in a specific location. Mission-based forecasting uses stratified sampling to create forecasts for different mission sets in different environments. The concept of mission-based forecasting was first introduced in a 2005 government consulting group study by the Logistics Management Institute (LMI) and further articulated in "Transforming U.S. Army Supply Chains" (Parlier, 2011). Using Army aviation units as a test bed, LMI looked at repair part (US Armed

Forces Class of Supply IX–Class IX) demand for AH-64 Apaches during training in the continental United States (CONUS), major combat operations (MCO) in Iraq, and stability operations (Stab) in Iraq. Looking at an AH-64 helicopter unit in these three scenarios resulted in data that was broken down by mission type (Training versus MCO versus Stab) and environment (temperate CONUS versus Iraqi desert). Results of the research are presented in Figure 1 with part demands given as percentages in the Venn diagrams.

The intersection of each Venn diagram represents the part demand during CONUS operations and operations in Iraq. The aggregated demand for all of these parts (part depth) was 4.4 times higher during MCO in Iraq than during CONUS operations and 3.9 times higher during stability operations in Iraq. Additionally, the Venn diagrams portray a large percentage of parts demand seen during CONUS operations that is never seen in Iraq and vice versa (part breadth).

The Department of Defense has many planning tools at its disposal and uses different ones depending upon the agency and type of analysis needed. Although each planning tool is useful and provides helpful analysis, none offer end-to-end analysis of the entire sustainment system. In addition, none of the tools in the



**Figure 1.** Part demand. Relative composition and magnitude for AH-64D Apache comparing CONUS part demands with major combat operations in Iraq (left) and stability operations in Iraq (right). Percentages are for part demands (Parlier, 2011).

following list interfaces with an ERP system to exploit the existing logistical data. Many of the well-known logistic planning tools have a focus outside of sustainment supplies and so will not be discussed. The following is a nonexhaustive list of planning tools, but covers some of the more widely used tools or tools more closely aligned with the capabilities of the Military Logistic Network Planning System (MLNPS) presented in this article:

- *Analysis of Mobility Platform*: AMP is the most similar to the MLNPS. Unlike many other planning tools found during research, AMP allows end-to-end modeling but requires sequential tools to achieve this perspective. AMP is a modeling and simulation application used for analyzing the end-to-end transportation of equipment, passengers, and supplies through the defense transportation system. AMP is used widely by the US Transportation Command (TRANSCOM) in providing an understanding of the overall transportation capabilities needed for long-term strategic planning (Anonymous, 2001).
- *Logistic Battle Command*: LBC is a discrete event simulation capable of theater-level modeling and sustainment planning and verification (TRAC-LEE, 2015). The model is used primarily by the Army Training and Doctrine Command's Analysis Center at Fort Lee, Virginia. LBC is a highly flexible model that can be adapted to help answer a multitude of logistical problems/questions. It can model large scenarios with as many as 18 brigade combat teams (BCT) or help generate a schedule of resupply convoys for a single BCT.
- *Planning Logistics Analysis Network*: PLANS is a web-based logistics planning tool being built by the US Army Engineer Research and Development Center (ERDC). Although still in the design phase (at the time of this writing), the model has the potential to be powerful in planning in-theater logistical operations. It is not an end-to-end model. The model takes a detailed, micro look at all in-theater logistical operations (personal communication from Corey Winton during 2015 visit to the ERDC). From weather pattern impacts on roads and soils, to the efficiency of individual forklifts in a warehouse, the

strength of this model is in the details. Although a micro analysis of a network is important, it is not the focus of the MLNPS.

## MODELING THE NETWORK

The path of a requisition transiting the military supply network includes handling at numerous logistical nodes and transit on multiple transportation assets. Handling at a logistical node includes operations such as pulling a part off a shelf at a supply warehouse (pick-and-pack operations), palletizing/containerizing supplies for air/sea movement, and breaking down pallets and separating by ordering unit. The combination of supply node, demand node, and mode of transportation determines which logistical nodes and transportation assets supply transit. Each node is modeled as a machine in a factory where jobs (requisitions) are required to queue until the machine becomes available at which time they are processed with deterministic processing times. The logistic nodes and transportation assets are referred to as processors and are assigned a processor number. Each processor number is assigned a processor type, where each type represents a specific function within the logistical network. Figure 2 shows the path a requisition must take from point of supply to point of consumption in Iraq. The Iraq network is shown here because it will be used later to validate the model, but similar networks exist for other customers throughout CONUS and the world.

When a requisition is entered into GCSS-Army, there is a period of time when the Defense Logistics Agency (DLA) determines the proper mode of transportation, and from which distribution center (DC) the requisition should be sourced. This is called the order-and-source time. Once a requisition is sourced to a specific DC, those supplies must be pulled from the warehouse shelves and packaged (usually in a multipack box) for shipment (pick-and-pack operations). Requisitions that are sourced at a DC not co-located with the consolidation and containerization point (CCP) must be shipped on a commercial truck to the CCP. Once at the CCP, requisitions/multipacks are loaded onto 463L pallets and, if being routed by sea, packed

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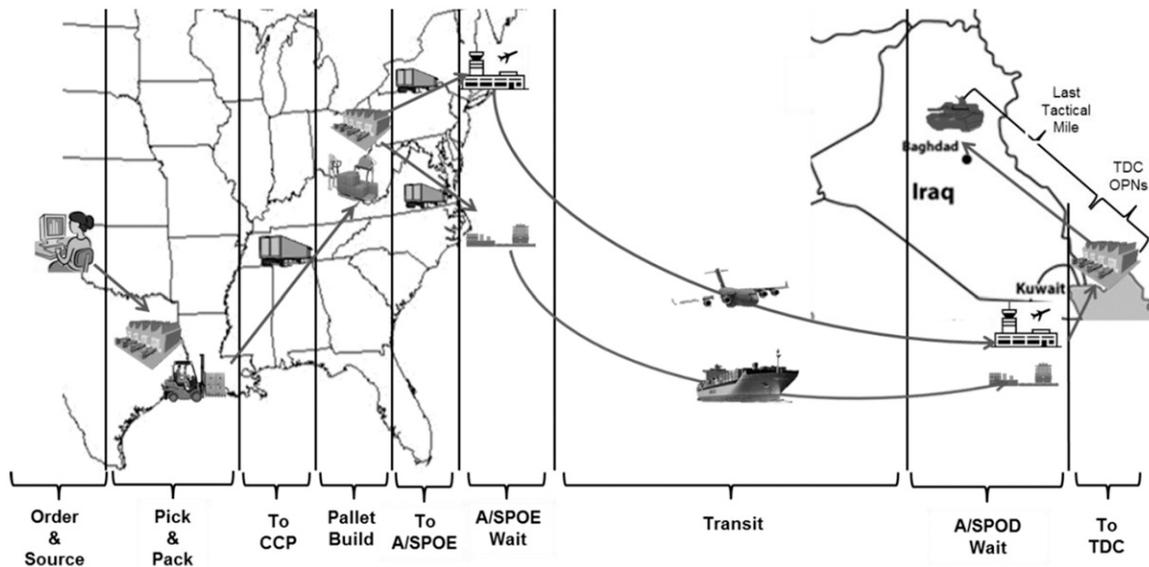


Figure 2. Requisition path from the Continental United States to Iraq.

into 40-foot containers. Pallets and containers are shipped from the CCP to the airport of embarkation (APOE) or seaport of embarkation (SPOE) on commercial trucks. Once at the APOE (SPOE), pallets and containers are loaded onto aircraft (ships) as they become available. When the pallets (containers) arrive at the port of debarkation (APOD/SPOD), they are downloaded and prepared for movement to the theater distribution center (TDC). The containers and pallets are then moved to the TDC via both commercial and military trucks depending upon availability. Operations at the TDC consist of breaking down pallets and containers and re-sorting requisitions by unit. Supplies are moved between the TDC and the ordering unit with military trucks only because the roads are in a combat zone. This final movement of supplies is commonly referred to as the last tactical mile (LTM).

Each of the logistical elements seen in Figure 2 is represented by one of seven different types of Virtual Factory processors. Each processor has unique characteristics but can represent more than one type of logistical element in the network. These processors govern the logic followed by the model at each logistical node in the network. The processors allow for the modeling of order fulfillment at a distribution center, aggregating multiple shipments onto a pallet, loading a shipping container,

transporting with a single truck, or breaking down containers and pallets prior to final delivery. These processors form logical building blocks with which we describe and model each logistical node in the network.

The logistical network is modeled using a processor for each logistical node and transportation asset. Each requisition is assigned a path of processors it must transit, simulating the path it must take in the logistical network. Each requisition is also given a due date based on the final destination and priority in accordance with Army regulations (for more detail, see US Department of the Army [1995, 1997] and Rogers [2016, section 3.2]). Processing times are assigned for each processor to represent the time it takes to process a requisition at each logistical node, though requisitions will also experience waiting times as they queue for each processor. The model requires a mission-based forecast for the sustainment supplies needed for an operation to simulate the movement of the supplies through the network using the Virtual Factory's sequencing procedure. Network details and underlying assumptions can be found in Rogers (2016, section 3).

The setup and operation of the MLNPS is represented in Figure 3. When a contingency mission is identified, the composition of the logistical network must be identified and created

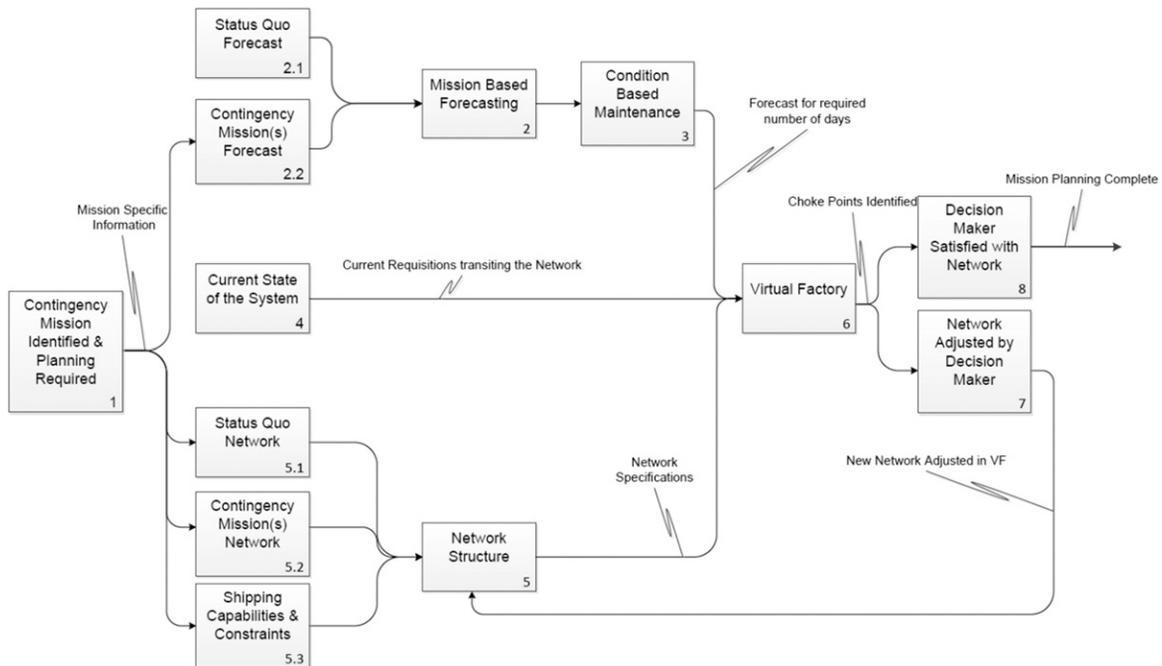


Figure 3. Military Logistics Network Planning System flow chart.

using processors (box 5.2). Coupled with the existing, “Status Quo,” network (box 5.1) and shipping capabilities and constraints (box 5.3), the logistical network structure is created. The mission-based forecast consists of the home station, “Status Quo,” units (box 2.1) and the units conducting the contingency mission (box 2.2). This mission-based forecast and the parts already transiting the system (box 4), obtained from ERPs, make up all of the sustainment requisitions to be simulated. The network structure and requisitions are entered into the Virtual Factory (box 6) and the simulation is run. Choke points are identified by the amount of queuing at logistical nodes. A decision maker must then determine if the queuing is acceptable or if the network capabilities need to be adjusted to reduce queuing. If the decision maker is satisfied (box 8), the logistical planning is complete and required capabilities are identified. If not satisfied (box 7), the network structure is adjusted (i.e., assets are added to the network) and the simulation is run again. This process of observing the queuing time and adjusting the network continues in an iterative manner until the decision maker is satisfied with the logistical plan.

Once the Virtual Factory was adapted to meet the needs of the MLNPS, the model was validated by comparing the model results to data from an actual network. This was done by simulating the movement of the requisitions during OIF and comparing the actual queuing seen in the network (as recorded by the RAND study) with the queuing from the model. The data set that was used in the 2005 RAND study (Peltz et al., 2005) was obtained. The dataset had all requisitions (years 2003–2004) from OIF as the data points on network performance in transporting those requisitions through the network. Only a portion of the OIF dataset was used when validating the model. Requisitions with release dates two weeks prior to forces crossing into Iraq through the end of May 2003 were simulated. This sub-dataset consisted of approximately 1.96 million requisitions with release dates spanning an 87-day period. We focused our analysis on the first 12 weeks of the war because after that amount of time, the force structure, geopolitical situation, mission set, the disposition of enemy and friendly forces, and even the logistics system changed significantly. Approximately 647,000 of these requisitions were destined for units in Iraq or Kuwait, with

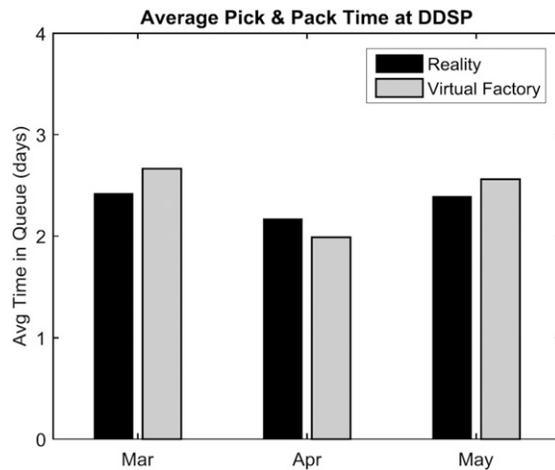
the remaining approximately 1.3 million requisitions destined for units in CONUS or elsewhere in the world. The 1.3 million requisitions not going to OIF were included in the simulation because they went through the same primary distribution center, Defense Depot Susquehanna, Pennsylvania (DDSP), as those that went to OIF and thus they competed for the same resources.

The dataset did not include Class I (food and water) and Class V (ammunition). Since CL I and CL V supplies use a significant amount of transportation assets, they had to be added to the model. Estimates for these supplies were calculated using planning factors found in Army field manuals and added to the requisition forecast.

Before continuing, it is important to distinguish between what will be referred to as “actual” conditions and “originally planned” conditions. The logistical plan for OIF and what actually happened differ in multiple areas. For example, during planning, logisticians determined that 965 (“originally planned”) military trucks were needed to transport supplies from the TDC in Kuwait to troops in Iraq (Peltz et al., 2005). When forces crossed the line of departure into Iraq, there were only 191 (“actual”) trucks available. Other planned versus actual numbers as well as how the values were used in the model can be found in Rogers (2016).

The model was run with “actual” planning conditions and compared to how the network actually performed (reality). This is done by comparing the model results with either the empirical evidence from the OIF dataset or using anecdotal evidence from OIF after-action reviews (AARs). Queuing at critical nodes along the network path, found in Figure 2, was compared. All of the nodes were analyzed but only those four with measurable queuing are discussed. The first two nodes are compared using empirical evidence from the OIF dataset. The first statistic compared is the pick-and-pack time at the DDSP, the primary distribution center for supplies going to OIF. Figure 4 shows the by-month average pick-and-pack time comparison for March to May 2003.

The average pick-and-pack time from the model and dataset are quite similar, with a maximum difference of 0.24 days for any

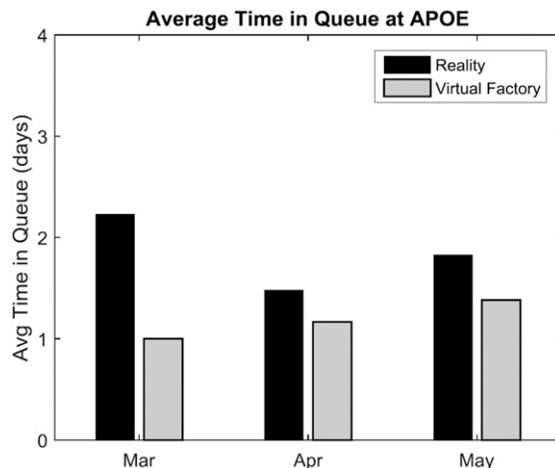


**Figure 4.** Monthly average pick-and-pack time at the Defense Depot Susquehanna, Pennsylvania.

month. Considering the smallest time unit of the simulation is days, this shows that the model can very closely represent what really happened at DDSP.

The next node that had significant queuing was the APOE. Figure 5 shows a comparison of by-month average time in the queue at the APOE. The difference in APOE queue time between the model and dataset is more significant than at DDSP, but is no more than a little over a day for any of the three months.

The last two nodes discussed are compared using anecdotal evidence, because the in-theater queue times were not available in the



**Figure 5.** Average time in queue at the airport of embarkation.

OIF dataset due to the difficulties in tracking the supplies once they arrived in Kuwait. The anecdotal evidence comes from AAR comments stating that repair parts did not start arriving, uninterrupted, into Iraq until around May 1, 2003 (Fontenot, 2005).

The first node that showed significant queuing during the first 90 days of OIF was the TDC in Kuwait. Figure 6 shows the by-day average time a requisition was in queue at the TDC.

In addition to the by-day average time in the queue, Figure 6 also shows the staffing level of the TDC with a secondary axis and line plot superimposed on the graph (Peltz et al., 2005). The day that coalition forces crossed the line of departure from Kuwait into Iraq is also depicted on the graph to understand when forces were actually in Iraq waiting for supplies. The star marks the approximate day requisitions began consistently arriving at ordering units. It is important to point out that queue times do not

include any requisitions for CL I or CL V. The graph shows that there is no significant queuing until a little over a week after forces entered Iraq. This can be explained by the fact that few supplies were ordered until forces had a tactical pause in fighting and were able to put supplies on order. Once the ordering began, around the end of March, requisitions were in the TDC queue for a significant amount of time. This significant queuing can likely be explained by the fact that there were only 200 personnel working in the TDC and their primary focus was getting CL I and CL V into Iraq. The model had queuing that reached nearly 45 days before the TDC was able to start working off the backlog and reduce the queuing time. The point at which the model begins to show a significant drop in average queue time coincides with the May 1 date that AAR comments suggested parts began arriving uninterrupted to forces in Iraq. Although a direct comparison to the actual

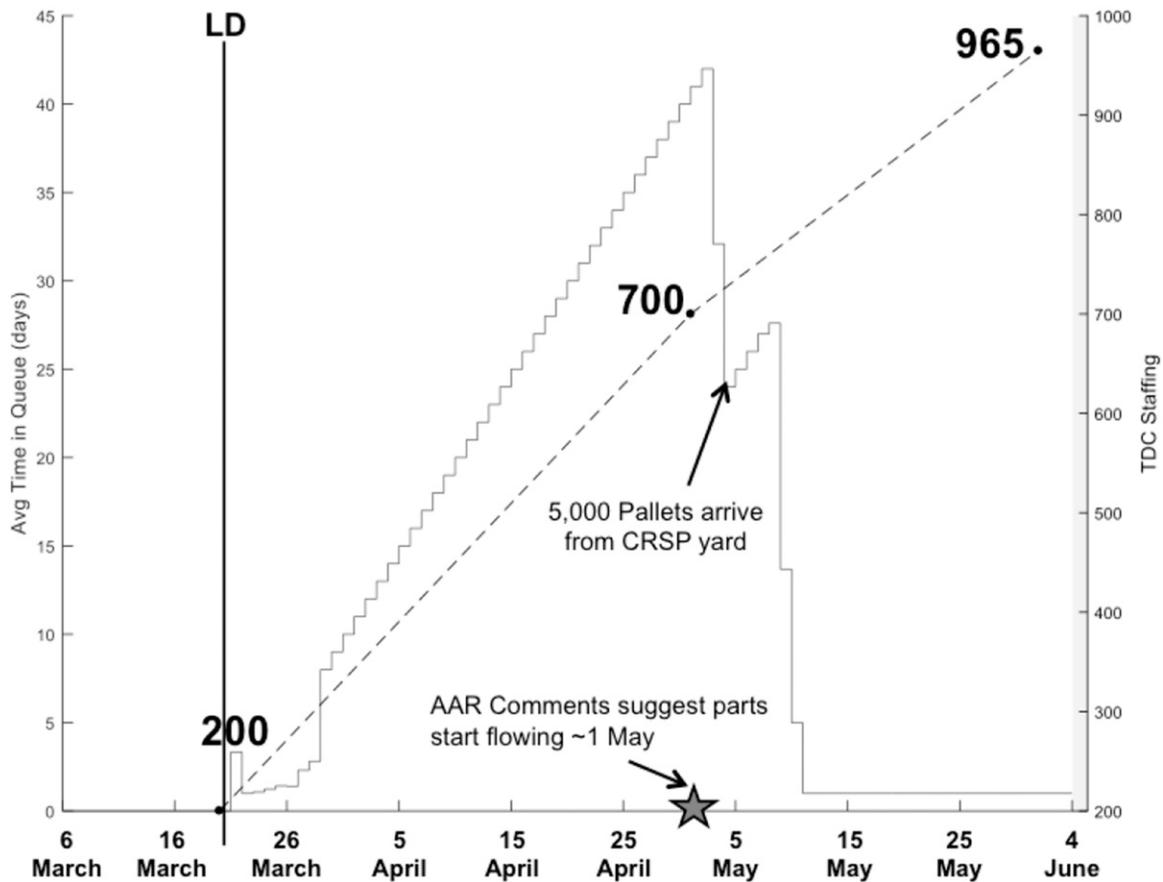


Figure 6. Average time in queue at the theater distribution center (TDC).

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queuing at the TDC was not possible, the queuing from the model mimics what actually happened based on the available anecdotal evidence.

The last node that showed significant queuing during the first 90 days of OIF was the processor that represented the LTM trucks. Figure 7 shows the by-day average number of requisitions waiting to be moved by the LTM trucks.

In addition to the by-day number of requisitions in the queue for LTM trucks, Figure 7 shows the number of LTM trucks on hand for operations with a secondary axis and line plot superimposed on the graph (Peltz et al., 2005). The graph shows that from the point when

forces crossed into Iraq, the number of requisitions in the queue increased steadily until approximately April 10. A series of events contributed to the extensive queuing. First, as already discussed, 191 of the required 965 trucks were available when forces crossed into Iraq on March 20, 2003. Next, on March 23, a sandstorm crippled logistics for a three-day period (Peltz et al., 2005). No trucks or aircraft were able to provide any type of resupply to troops in Iraq.

When the sandstorm finally cleared on March 26, the LTM trucks were re-tasked to move troops. Once trucks were finally available for resupply operations on March 31, troops in Iraq were in dire need of CL I and CL V (food,

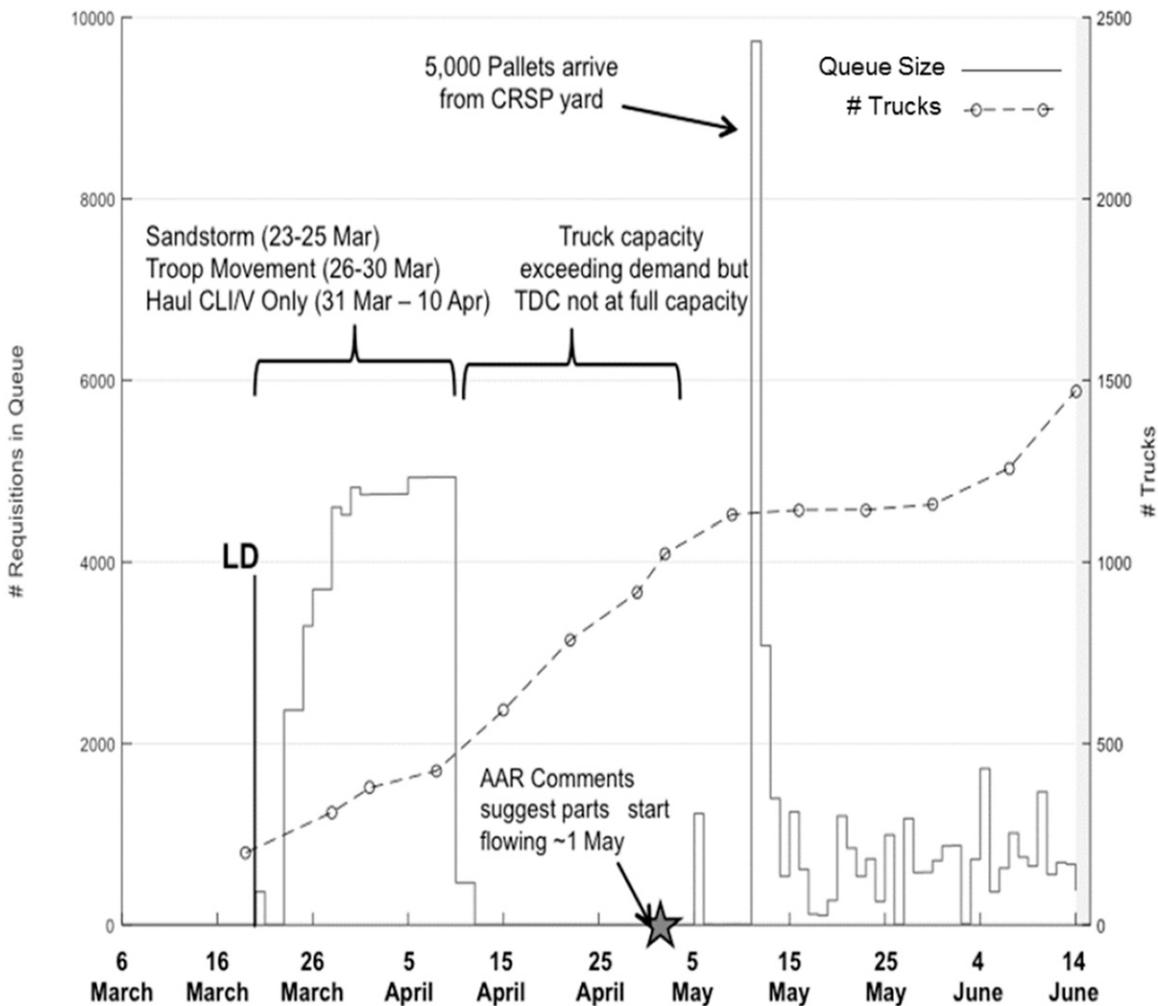


Figure 7. Average number of requisitions in queue for last tactical mile trucks.

water, ammunition) resupply. To bring unit on-hand supply up to the appropriate levels, the available LTM trucks were filled almost exclusively with CL I and CL V. This helps explain why the backlog of requisitions was not immediately worked off in the model. Analysis with these model inputs indicates that sufficient LTM capacity for CL IX was not achieved until approximately April 11. This did not, however, lead to an uninterrupted delivery of supplies. The TDC was still not operating at full capacity on April 11 (see Figure 6), which resulted in requisitions only trickling out until approximately May 5. This is the point at which the model shows uninterrupted delivery of requisitions to units in Iraq. Just as with the TDC queuing, LTM truck queuing from the model mimics what actually happened based on the available anecdotal evidence.

### USING THE MLNPS TO PLAN OPERATION IRAQI FREEDOM

To demonstrate the MLNPS' utility in planning the logistical network for a contingency operation, the analysis required the OIF dataset as an input. Since many of the planning factors for OIF are known, the MLNPS was used to model the OIF network under originally planned conditions. The originally planned factors are what OIF planners determined were needed, using the planning tools they had at the time and the tactical plan for OIF. The model was run with the originally planned input values and the network performance was analyzed. The network performance from the model was compared to how the network was performing, in terms of queuing, prior to the start of OIF. For the first 90 days of operations, the model did not show significant queuing at any node. This shows that if the OIF logistical network had been established as planned, it would have run without any excessive queuing for the first 90 days of operations. The model was then run for the first 365 days of the operation, using all of the requisitions from 2003 (~7.67 million requisitions). Significant queuing was observed for the pick-and-pack operations at DDSP. The queuing did not occur in the first 90 days, but shortly after began to steadily

increase until queuing exceeded 25 days in December 2003. Figure 8 shows the queuing that the model predicted.

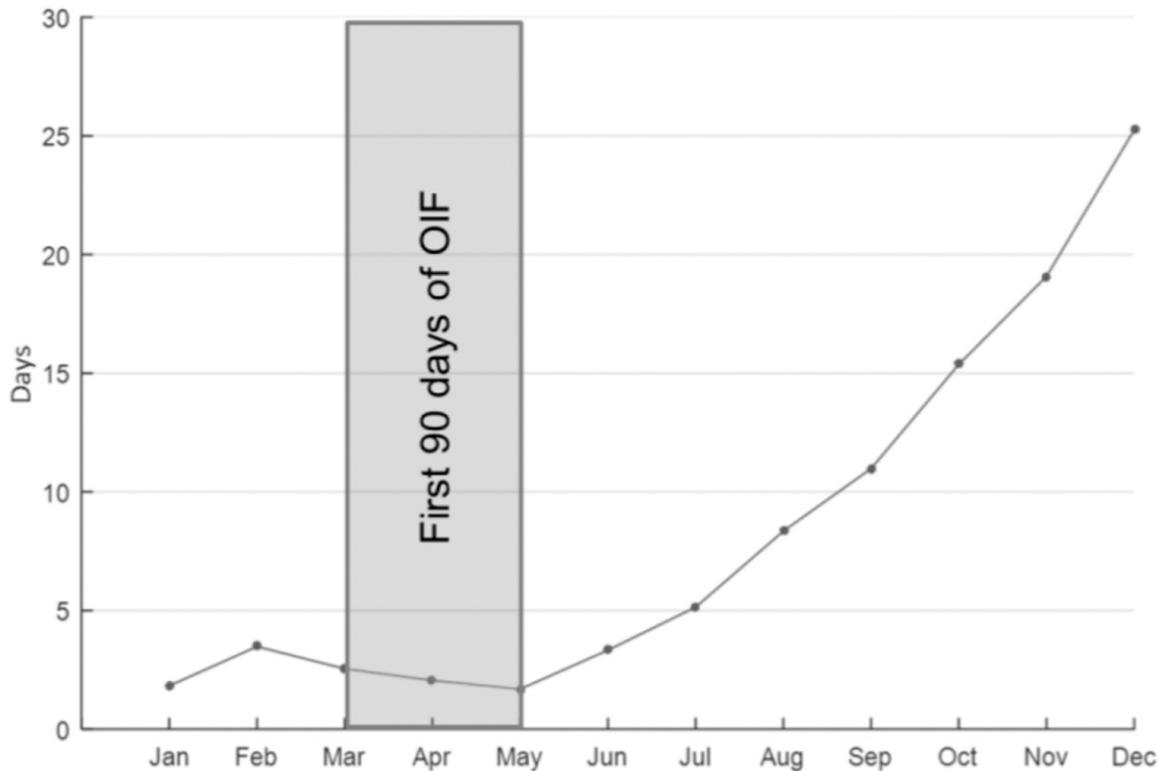
As planned, it was thought that DDSP capacity at the start of OIF would be sufficient to handle the requirements of OIF. What actually happened? At some point during OIF, DDSP received indicators that the demand was exceeding the capacity. DDSP had to hire 400 additional workers to work off the requisition backlog and prevent further backlogs (Peltz et al., 2005). The indicators were not seen with enough time to hire the 400 workers needed to prevent significant queuing. By the time the additional 400 workers were able to start working off the backlog of requisitions, the queuing had reached almost 12 days by August. Figure 9 shows the comparison of monthly queuing predicted by the model (without any increase in capacity) and the actual queuing from the OIF dataset (with the increase in capacity from 400 additional workers).

As Figure 9 shows, the hiring of 400 additional workers resulted in DDSP eventually getting the queuing under control by the end of 2003; however, the peak queuing of 12 days was unacceptable and had profound downstream network impacts (Peltz et al., 2005). Ideally, DDSP should get bottleneck indicators earlier so it can hire workers in time to prevent queuing from exceeding three to four days. The results show that the MLNPS tool can forecast significant queuing in time for capacity to be properly adjusted.

The MLNPS was run with adjusted capacities until the queuing was at acceptable levels for the duration of 2003. Figure 10 illustrates how capacities were increased iteratively to achieve these acceptable levels of queuing; the right graph shows the third iteration resulting in the final solution.

After three iterations of capacity adjustments, the model queuing appears to be under control. With additional capacity of 3,000 requisitions per day (15 percent increase in capacity) added in May and 500 added in November, DDSP would be able to handle the volume of requisitions associated with the increase of BCTs fighting in Iraq. There could be more efficient solutions, and working with DDSP to plan a more phased hiring plan would almost

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**Figure 8.** Average pick-and-pack times at Defense Depot Susquehanna, Pennsylvania, for 2003 according to model (as planned). (OIF: Operation Iraqi Freedom)

certainly be better than the incremental capacity changes used in the three iterations. This does, however, illustrate how the MLNPS could be used to forecast and then eliminate queuing at a distribution center. What is not shown, but cannot be ignored, is the potential downstream network improvements created by reduced queuing at DDSP.

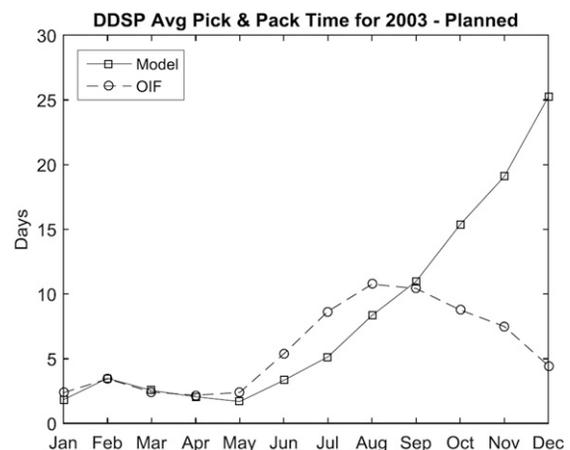
The MLNPS could also have been used to determine how many trucks could be cut from the originally planned 976 trucks and still sustain OIF combat operations. To demonstrate this, the model was initially run with 200 LTM trucks (197 trucks were actually present). Figure 11 shows that significant queuing occurs with only 200 trucks.

When the number of LTM trucks is increased to 300, there is no significant queuing, indicating that 300 trucks would be sufficient for the first 90 days of operations (see Figure 12).

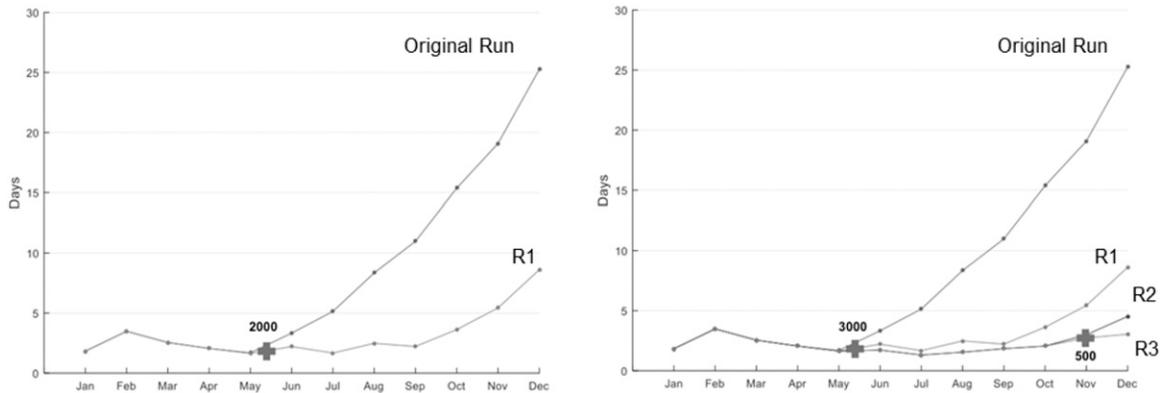
Knowing that 300 trucks was the minimum needed for the start of operations, planners could have ensured that the extra 100 trucks

were not delayed in arriving to Kuwait but still diverted the remainder with confidence.

With the MLNPS validated as a credible tool for predicting performance of the Army's logistical



**Figure 9.** Average pick-and-pack time at Defense Depot Susquehanna, Pennsylvania, as planned versus actual OIF.



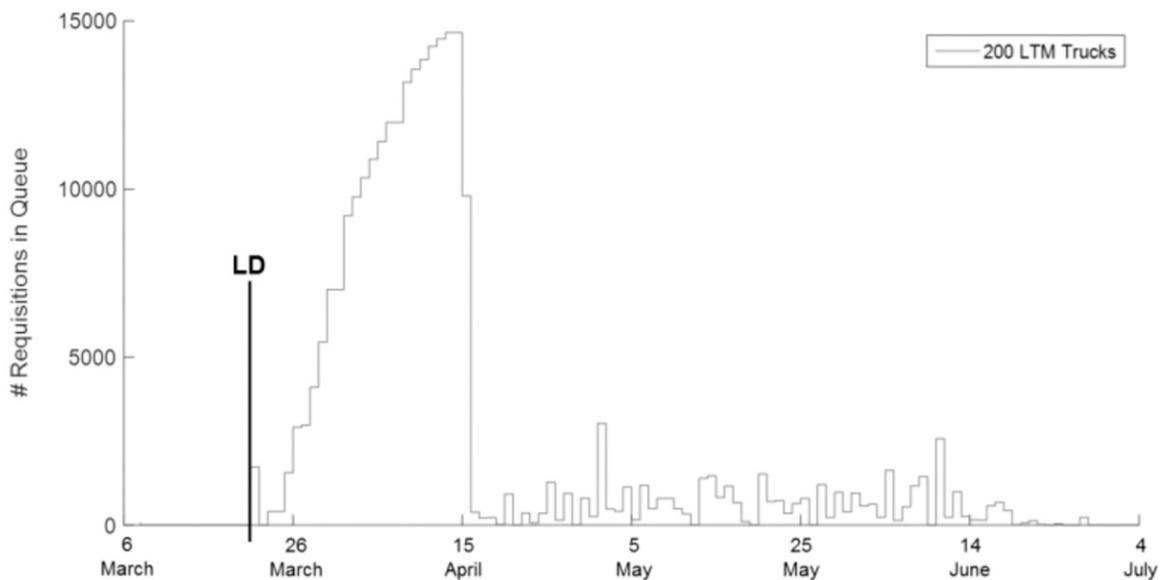
**Figure 10.** Average pick-and-pack time at Defense Depot Susquehanna, Pennsylvania, with added capacity. (a) First iteration: +2,000 requisition capacity/day in May; (b) Final: +3,000 requisitions/day starting in May and +500 requisitions/day starting in November, R1: +2,000 requisitions capacity/day in May, R2: +3000 requisitions capacity/day in May, R3: +3,000 requisitions capacity/day in May and +500 requisitions capacity/day in November.

system, the next step is to show how it could be used to help plan contingency operations.

### USING THE MILITARY LOGISTICS NETWORK PLANNING SYSTEM TO PLAN A NOTIONAL OPERATION

To use the MLNPS to plan the logistical network for an expeditionary operation, a

notional operation had to be created. The background for the notional operation is that the Islamic State in Iraq and Syria (ISIS) has moved equipment and fighters from Libya into the bordering country of Sudan. The Sudanese government is harboring these fighters and facilitating the planning and execution of attacks on bordering countries. ISIS is using the safe haven in Sudan to stage attacks in other countries in Africa, mainly in South Sudan. The international community has condemned the



**Figure 11.** Number of requisitions in queue for 200 last tactical mile (LTM) trucks.

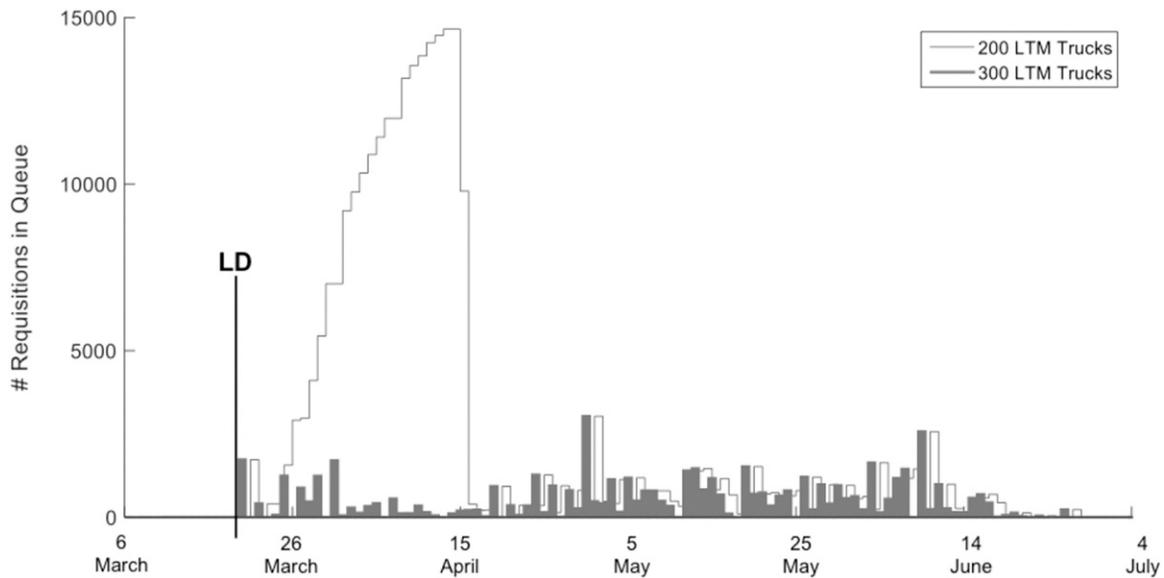


Figure 12. Number of requisitions in queue for 300 last tactical mile (LTM) trucks.

actions of the Sudanese government in harboring ISIS. The United States sees the presence of ISIS in Sudan as a threat to African allies and a tremendous instability in the region. The United States has committed to helping protect South Sudan and other African allies. The mission for the US is to destroy ISIS troops and equipment in Sudan in order to prevent their ability to conduct attacks in Africa.

With the concentration of ISIS fighters in the capital of Khartoum and the impoverished Darfur region, the mission requires two US BCTs. The plan calls for one infantry BCT (IBCT) and one Stryker BCT (SBCT). The SBCT will conduct operations in the Darfur region and the IBCT will operate in Khartoum. Table 1 presents the entire task organization (troops required) for the operation.

This task organization is mainly used to create the requisition forecast in lieu of an actual mission-based forecasting.

The path a requisition travels for the Sudan operation is similar to OIF except for the geographical differences once the supplies go overseas. Figure 13 shows the path of a requisition.

There are many ways to get forces into Sudan, but for this notional operation the SPOD is the port of Mombasa, Kenya. The TDC is established in South Sudan, which borders the

hostile nation of Sudan. It is assumed that the truck network in Africa is not sufficient to transport the shipping containers; therefore, military trucks must be used for all trucking operations. The APOD is located in South Sudan and in close proximity to the TDC.

Because there is no mission-based forecast for this notional operation, nor is there a dataset to act as a surrogate, a forecast had to be generated. The forecast was generated using numerous properties of the OIF dataset. For each characteristic, a unique distribution was fit using Stat::Fit<sup>®</sup>. When there was a correlation between two characteristics, the Gaussian copula method (Pham, 2006) was used to allow for generation of two characteristics while maintaining the correlation between the two.

Table 1. Notional Sudan mission task organization.

| Task organization                             |
|---|
| 1 x Infantry Brigade Combat Team              |
| 1 x Stryker Brigade Combat Team               |
| 1 x Engineer Battalion (construction effects) |
| 1 x Sustainment Brigade                       |
| 1 x Aviation Battalion (attack and lift)      |
| 1 x Division Headquarters                     |
| 3 x Battalion miscellaneous enablers          |

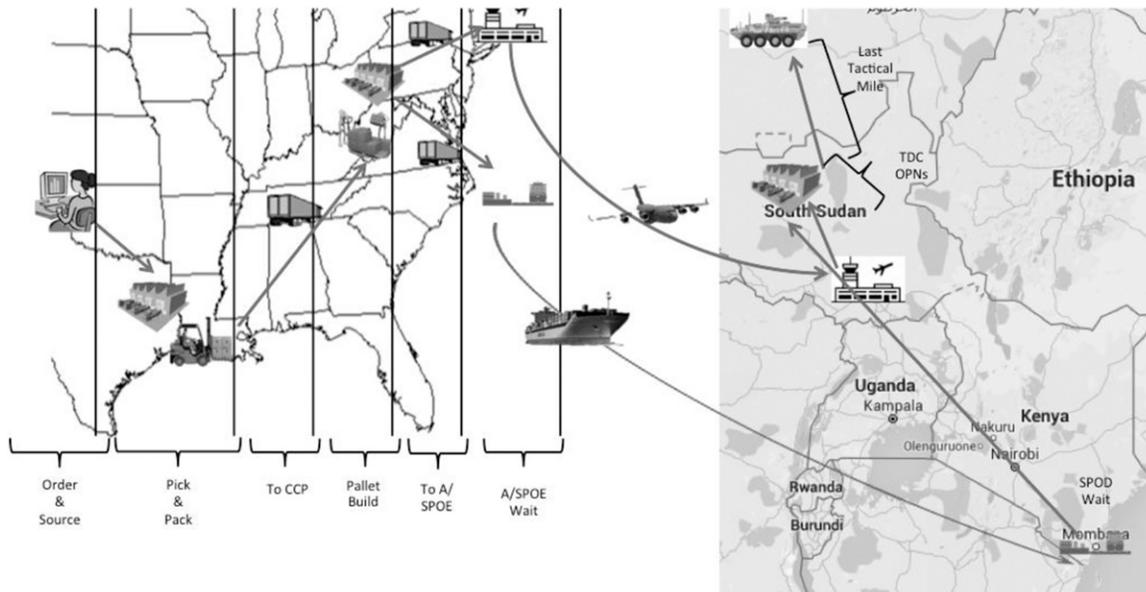


Figure 13. Requisition path from the Continental United States to Sudan.

Up to this point, everything modeled was assumed to be deterministic. Because of the deterministic nature of the models, single data points were used during analysis of the networks. Random generation of the requisition forecast introduces a stochastic element to the model. Because single data points cannot necessarily be used with stochastic modeling, analysis had to be done to determine the number of data points needed to provide reliable results. Five forecasts were generated and simulated, and the variability in queuing at each of the critical nodes was analyzed. For each critical node, all five data points were compared. The results showed that across all critical nodes, the maximum half-width for queuing time for any day at any node was 0.336 days or just over eight hours. Considering the smallest time unit of the simulation is days, a maximum half-width of eight

hours is not significant. Thus, all further analysis was done using a single data point.

Because of the long distance between the SPOD and units in Sudan, network planning includes looking at two different locations for the TDC. The first location for the TDC is in the capital of South Sudan, Juba. Placing the TDC in Juba decreases the distance between the SPOD and TDC, but increases the distance between the TDC and the units in Sudan. Placing the TDC in Juba will be referred to as Course of Action (COA) 1. The alternate location for the TDC is in the city of Wau (referred to as COA 2), which is closer to the border with Sudan, decreasing the distance between the TDC and the units in Sudan but increasing the distance between the SPOD and TDC.

Each COA has distinctly different travel times for the trucks transporting supplies.

Table 2. Round-trip convoy times for each course of action (COA).

| Travel leg           | COA 1 (Juba)       | COA 2 (Wau)        |
|----------------------|--------------------|--------------------|
| SPOD to TDC          | 7 days round-trip  | 10 days round-trip |
| TDC to IBCT in Sudan | 10 days round-trip | 8 days round-trip  |
| TDC to SBCT in Sudan | 8 days round-trip  | 8 days round-trip  |

Notes: IBCT: infantry brigade combat team, SBCT: Stryker brigade combat team, SPOD: seaport of debarkation, TDC: theater distribution center.

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**Table 3.** Course of action (COA) 1 required capacities.

| Critical node        | COA 1 capacity*            |
|----------------------|----------------------------|
| DDSP                 | 2,100 requisitions/day     |
| APOE                 | 25 pallets/day             |
| APOD and SPOD trucks | Five truck companies       |
| TDC                  | 500 pallet equivalents/day |
| LTM trucks           | 7 truck companies          |

\* The unit of capacity is specific to each node.

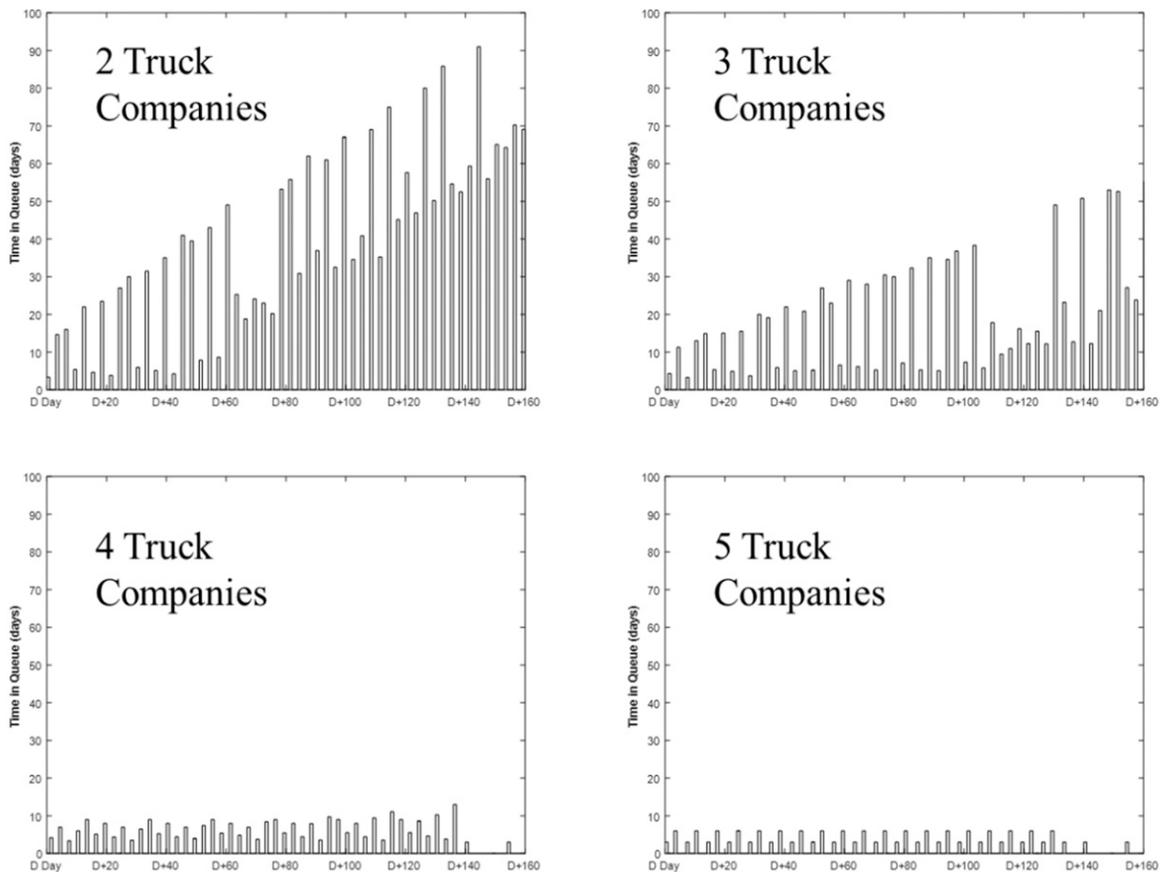
Notes: APOD: airport of debarkation, APOE: airport of embarkation, DDSP: Defense Depot Susquehanna, Pennsylvania, LTM: last tactical mile, SPOD: seaport of debarkation, TDC: theater distribution center.

Round-trip times for convoys vary between six and 10 days. The travel time was determined using the road distance from [www.google.com/maps](http://www.google.com/maps), and a march rate of 30 kilometers per hour. Table 2 summarizes the round-trip times used for each COA.

For each COA, the MLNPS was used to determine the capacities needed for each of the critical nodes. The critical nodes analyzed for this operation are DDSP, APOE, APOD, and SPOD trucks, TDC, and LTM trucks. Once the MLNPS is used to determine the capacities needed at each critical node for each COA, the COAs are compared and a COA is recommended to the commander.

When determining the capacity needed at each node, a decision maker would determine the amount of queuing that is acceptable at each node. In lieu of a decision maker, historical average delay times were used. Table 3 displays the results of COA 1 analysis by listing the required capacity for the five critical nodes.

The process of determining the capacities needed at the APOD and SPOD truck and LTM truck nodes are next presented to show how the MLNPS can be used to plan. First the required number of APOD and SPOD truck companies



**Figure 14.** Seaport of debarkation queuing for course of action 1.

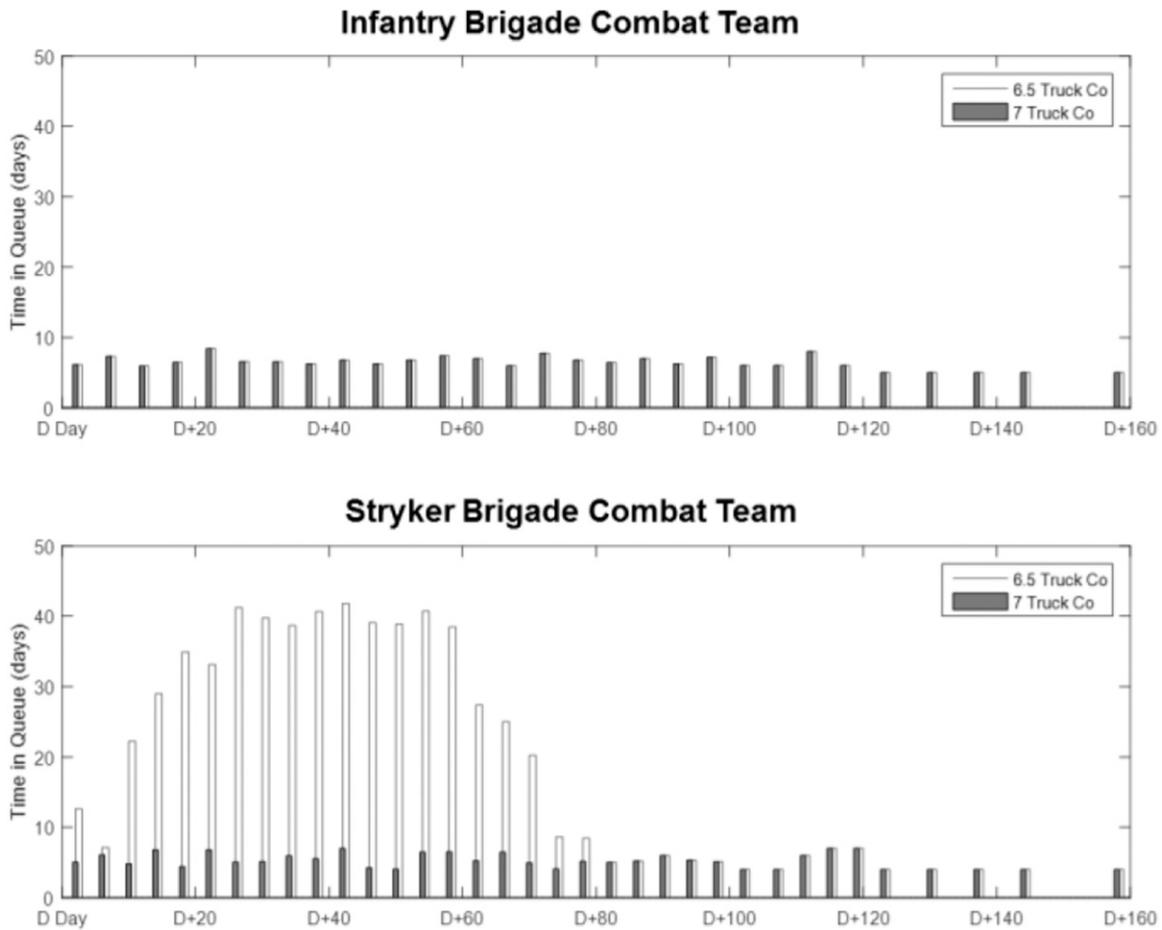


Figure 15. Last tactical mile queuing for course of action 1.

was determined by iteratively increasing the number of truck companies until queuing was at an acceptable level (see Figure 14).

With five truck companies, the queuing is reduced to an average of approximately three days for the duration of the operation. It appears now that the queuing is due to the round-trip time of the trucks, not due to insufficient capacity on the trucks when they depart.

In the same iterative manner, the required number of LTM trucks was determined (see Figure 15). Each BCT was looked at separately because they are in two different locations.

With seven truck companies, queuing is reduced for both BCTs to a level of queuing that appears to be because of round-trip time. The recommended number of truck companies to dedicate to LTM operations is therefore seven.

The same procedure was done for COA 2 with the results found in Table 4.

As expected, the number of APOD and SPOD truck companies increased and the

Table 4. Course of action (COA) 2 required capacities.

| Critical node        | COA 2 capacity             |
|----------------------|----------------------------|
| DDSP                 | 2,100 requisitions/day     |
| APOE                 | 25 pallets/day             |
| APOD and SPOD trucks | 7 truck companies          |
| TDC                  | 700 pallet equivalents/day |
| LTM trucks           | 6 truck companies          |

Notes: APOD: airport of debarkation, APOE: airport of embarkation, DDSP: Defense Depot Susquehanna, Pennsylvania, LTM: last tactical mile, SPOD: seaport of debarkation, TDC: theater distribution center.

number of LTM truck companies decreased. This is logical because the only differences in the two networks are the locations of the TDC.

With a combatant commander looking at two different COAs, they will receive a recommendation from each of the staff sections that represent the warfighting functions. For example, the staff section representing the protection warfighting function would probably recommend the COA that allows the forces to most easily secure the TDC and the convoys moving between it. For logistics, one has to look at the equipment and personnel needed to support a specific COA. A comparison is conducted to determine which COA is better. Table 5 shows the COA comparison with only those criteria that differ between the COAs. COA 1 is clearly the recommended option, outperforming COA 2 in each of the three distinguishing categories.

**USING THE MILITARY LOGISTICS NETWORK PLANNING SYSTEM TO PERFORM “WHAT IF” ANALYSIS**

Prior to the COA decision process, the MLNPS can be used to see how robust the plan is to potential changes. We chose to analyze the SPOD trucks to determine how sensitive the required number is to the extreme case of a disruption of the supply lines where the trucks are unable to move for seven days. This may be due to weather, a damaged bridge, enemy action, or many other potential reasons. Figure 16 shows the impacts of a seven-day disruption on the SPOD trucks.

The disruption causes an initial spike in queuing of approximately three days and then levels off to a near constant increase of one day. Because the queuing never returns to pre-disruption values, a reasonable conclusion is that the number of SPOD trucks does not make the

network robust enough to handle a seven-day disruption of the supply lines. If the decision maker agreed with this assessment, the number of SPOD truck companies would be increased and the sensitivity again tested for robustness. This type of analysis could be done at any of the nodes or for alternate “what if” questions (Rogers [2016, section 6.4] provides more examples).

In this article, the MLNPS was used only to plan the logistical requirements for an operation. It could also be used during an operation. It could be used to predict the impact of different operational scenarios on the logistical network. If, for example, a storm powerful enough to shut down air and ground logistical operations was approaching the area of operations, the MLNPS could be used to predict the impacts on the logistical network. The impacts could be presented to the commander, giving time to either adjust the logistical network or take other measures to mitigate the negative impacts.

**SUMMARY**

The model presented in this article looks at the end-to-end movement of sustainment supplies needed for supporting expeditionary operations. By modeling the repair part requisitions as jobs to be processed in a factory, we used an efficient scheduling heuristic to obtain a forecast for logistical performance. We demonstrate that this method is capable of predicting the location, timing, and magnitude of logistical backlogs (excessive queueing) using both data from OIF and a notional scenario. We also present a simple method to (1) determine the required capacities through the logistics network, and (2) assess the impact of a network disruption and the subsequent recovery.

**Table 5.** Course of action (COA) comparison.

| Comparison criteria                | COA 1 (Juba TDC)       | COA 2 (Wau TDC)        |
|------------------------------------|------------------------|------------------------|
| Required truck companies           | 12 truck companies     | 13 truck companies     |
| TDC capacity                       | 500 pallet equivalents | 700 pallet equivalents |
| Average total queuing (in theater) | 10.4 days              | 14.6 days              |

Note: TDC: theater distribution center

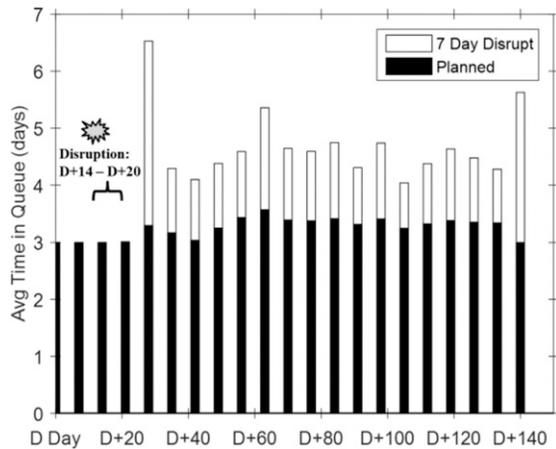


Figure 16. Seven-day disruption impact on seaport of debarkation queuing.

Most importantly, this paper contributes a proof of concept for a sustainment planning and decision-support tool that harnesses the Army’s ERP data and provides relevant information in a timely matter. To our knowledge, no other tool features this exploitation of real-time system data. We conclude that however useful this model is, GCSS-Army itself holds tremendous potential for analytical tools to assist military planners and decision makers.

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