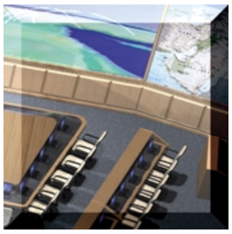

Linking Warfighting and Logistics

Charles H. Sinex, Stephen A. Basile, William A. Sellers, Daniel W. Kerchner, and Timothy C. Gion

Warfighting and logistics models have not been closely linked traditionally. The models used by the warfighting and logistics communities were designed for different purposes, required very different data, and did not consider model interoperability to be important. Consequently, there is no integrated model for developing and testing an integrated warfighting and logistics plan, making it difficult to evaluate new logistics concepts and systems for their ability to support the warfighter under all contingencies. The Warfighting Logistics Technology and Assessment Environment (WLTAE) Project showed that existing warfighting and logistics models could be linked in High Level Architecture distributed simulations to address these issues. This article describes the WLTAE development effort to date and possible extensions to new applications. (Keywords: ELIST, HLA, Logistics, Thunder.)

BACKGROUND

Logistics—the supply of personnel, equipment, and materiel to the front—has always been a critical factor in winning wars. In past wars, the U.S. military has generally taken a "just in case" approach to logistics. Massive amounts of supplies of all types were built up in the forward theaters to support the troops, and major offensives often did not commence until that buildup was well advanced. The 6-month buildup during Desert Shield, preceding Desert Storm, is a good example from recent history. Another characteristic of past wars is that the logistics pipeline was generally not significantly threatened, since the enemy could rarely seriously attack the logistics transportation system moving men and supplies from the United States to the theater of operations. Moreover, the major entry ports into the theater and the main logistics stockpiles within the theater were usually located well back from the front lines and were difficult for the enemy to attack with weapons of the time. On occasion, there have been exceptions to this rather benign environment for logisticians. For example, during World Wars I and II, German U-boat activity posed a serious threat to shipping from the United States to Britain and Europe.

Consequently, the logistics and warfighting communities have developed very different tools and models for their planning. Logistics tools tended to concentrate on scheduling and transportation modeling, with little or no allowance for the possibility of enemy attack on the various elements of the logistics infrastructure. On the other hand, warfighting models at the campaign level concentrated on developing and testing strategies, tactics, and new weapon concepts and generally assumed that unlimited supplies would arrive in the theater. When logistics is included within the campaign models, typically only the final stage of delivery from a storage depot to the warfighting troops is modeled. The flow of personnel, equipment, and supplies to these final depots is rarely affected by enemy action.

The circumstances that have allowed this separation of warfighting and logistics are rapidly disappearing, however. The large defense funding reductions since the end of the Cold War are now forcing reductions in the logistics infrastructure, and large inventories of equipment and supplies are no longer affordable. The commercial business world has shown that "just in time" delivery of supplies, coupled with real-time tracking systems, can significantly reduce inventory costs and increase productivity. Another factor is that Desert Storm clearly showed the world that our military was difficult to beat if allowed to build up its forces overseas until they were ready to go on the offensive. Nonetheless, the proliferation of theater ballistic missiles and weapons of mass destruction (nuclear, chemical, and biological) and the advent of information warfare now make it possible for our opponents to effectively attack the U.S. logistics pipeline. Moreover, such attacks might make it easier to deny the United States victory than a head-to-head military confrontation.

All of these developments have started a rethinking about military logistics. Faster delivery of supplies from the United States can reduce the need for large inventories of materiel overseas. Real-time tracking systems that show the location of orders in the logistics pipeline can confirm that shipments are on the way and give their arrival time. This increased visibility can prevent multiple orders for the same items, a situation that occurred in the past when there was no way to confirm an order. These changes, termed "lean logistics," can allow the warfighters to function effectively without the large buildup of supplies overseas. The changes also lead to a "reduced logistics footprint" in the theater, which can reduce vulnerability to enemy attacks against the logistics pipeline. In addition, the increased use of precision-guided munitions by the warfighters allows for reduced logistics requirements by increasing strike effectiveness and shortening the overall duration of a campaign.

This new logistics system, however, depends heavily on communications from the theater back to the continental United States (CONUS) and on extensive databases, opening new risks from information warfare. Because of lean logistics, there is also a much shorter time window for recovery if problems arise before the warfighters begin to run low on critical supplies.

BASIC CONCEPT FOR LINKING THE MODELS

Even though warfighting and logistics systems had become increasingly linked in the real world, no models or tools were available to study their interactions. This shortcoming led to the development of the Warfighting and Logistics Technology and Assessment Environment (WLTAE) in FY1997 to demonstrate the feasibility of linking these models and to study the issues identified.[1]

The basic concept behind WLTAE is illustrated in Fig. 1. WLTAE is an environment for linking existing models and databases to address warfighting/logistics issues. From the users' perspective, WLTAE includes a flexible interface that allows them to control, review, and analyze a simulated mission. The linkages between the models are made through the High Level Architecture (HLA) interface. The use of this architecture for

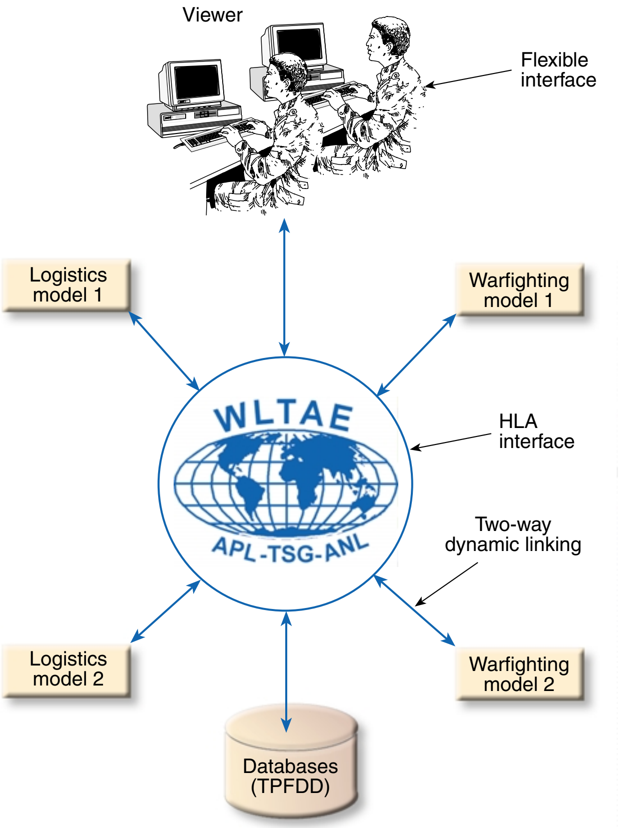

Figure 1. Basic elements of the Warfighting and Logistics Technology and Assessment Environment (WLTAE) concept. Key features include a flexible interface for reviewing, analyzing, and controlling the simulated mission; a High Level Architecture (HLA) interface to link models, decision support tools, and databases; and two-way dynamic linking that creates a collaborative process, enables realistic action/reaction, and identifies the impact of events on warfighting outcome. Participants in the WLTAE development effort are Argonne National Laboratories (ANL), APL, and The Spectrum Group (TSG) (TPFDD = Time Phased Force Deployment Data).

defense community distributed simulations was mandated by Paul Kaminski (Under Secretary of Defense for Acquisition and Technology) in 1997, and its adoption into WLTAE will make it easier to replace legacy models with future models developed for an HLA environment.[2]

WLTAE clearly requires a multidisciplinary approach, drawing on expertise in warfighting, logistics, modeling and simulation, and the new HLA interface. Consequently, a team approach was adopted for the WLTAE development effort. APL acted as the technical lead and provided expertise in modeling and simulation, HLA, and warfighting analyses; The Spectrum Group (Alexandria, VA) provided expertise on warfighting issues and needs from the commanders' perspectives; and logistics expertise was provided by the Logistics Management Institute (McClean, VA) and Argonne National Laboratories (Chicago, IL).

A key element in the WLTAE design was to dynamically link the warfighting and logistics models. Logistics shortfalls, such as delays or shortages in equipment or supplies (e.g., munitions), should be reflected in changes in the progress of a campaign. Possible campaign effects can include the cancellation of strike missions, increases in casualties and equipment losses, and a longer campaign, all of which can increase overall costs. Simultaneously, the logistics infrastructure—for example, the sea and air ports of debarkation (SPODs or APODs) from which supplies flow into the theater of operations, as well as the transportation networks within the theater—should be visible as targets to the enemy in the warfighting model. These infrastructure targets then must be defended by U.S. and allied forces. Successful enemy attacks on the logistics infrastructure result in reduced flow of supplies and equipment to the warfighters, thereby adversely affecting the progress of the campaign.

The simulation is being driven by the Time Phased Force Deployment Data (TPFDD), which describes the overall mobilization, deployment, and "sustainment" plan for a particular campaign. The TPFDD contains, for example, information such as the specific warfighting units that will be deployed to the theater, the transportation routes and modes (land, air and/or sea transportation) the units will take from their original CONUS locations to their final assembly areas in the theater, and the acceptable time windows for their arrival at various locations. The TPFDD also includes similar plans for the flow of sustainment supplies (e.g., food, munitions, fuel, repair parts).

In the WLTAE concept, various logistics transportation models would be used to move the units and supplies in the database forward to the theater of operations, where they would be handed off to the warfighting models to simulate the campaign. As seen in Fig. 1, the entire simulation would be started, monitored, and controlled by the viewer. The arrows indicate a dynamic feedback between the viewer/controller and all the models and databases during the simulation. This two-way linkage between the logistics and warfighting models has already been discussed. As soon as warfighting begins, the original warfighting plan starts to change, and the transportation plan represented by the TPFDD also needs to be adjusted to reflect the actual conduct of the campaign. Damage to the logistics transportation infrastructure can require additional changes in the TPFDD to redirect equipment and supplies to undamaged portions of the logistics infrastructure.

Defining the Mission Space

As already noted, the logistics chain extends from CONUS forward to the warfighters in a theater. Components in the chain are delineated by their geographical coverage. Strategic logistics describes the portion of the chain that extends from military facilities and factories in the United States to the APODs and SPODs at the entry to the overseas theater. This component includes transportation within the United States to the air and sea ports of embarkation and the strategic air and sea lifts overseas. Operational logistics covers the portion of the chain in the theater from the SPODs and APODs forward to the final distribution areas where equipment and supplies are turned over to the warfighters. The final portion of the chain covers the transport from these distribution points to the front lines and the forward air bases.

Since the TPFDD describes the planned flow of equipment and supplies along this entire distribution system, it is possible to set up a simulation that covers any portion of the chain. For example, one could assume that equipment and supplies arrive at the APODs and SPODs exactly as described in the TPFDD and only model the operational flow of the materiel forward to the warfighters. Alternatively, one could start the simulation at any point back to CONUS, assume that the TPFDD accurately describes the timing of supplies at that point, and then model the flow of the supplies forward to the warfighters. The proof-of-principle demonstration focused only on the operational and tactical logistics portion of the chain within the theater of operations. In addition, to ensure that the logistics system was realistically strained, the demonstration concentrated on campaign-level warfighting rather than mission-level combat. The next step was to select suitable models for this initial demonstration.

Selecting the Model

Many campaign-level and operational logistics models were examined for their suitability in this linked simulation. The goal was to identify two legacy models that could be realistically linked in this dynamic sense, not to select the best possible warfighting and logistic models.[1] The models had to meet five key criteria:

1. The warfighting model had to be sensitive to logistics shortages that could result in cancelled missions or lost ground and be able to include the logistics infrastructure (e.g., APODs and SPODs) as enemy targets to be defended by U.S. and allied forces.
2. The logistics model had to be able to reflect the impact of such enemy attacks in terms of their effects (e.g., reduced APOD and SPOD throughput rates, destroyed components of the transportation networks like bridges or railroads, etc.).
3. The models had to run in a start–stop step mode rather than a run-to-completion mode. Since most of the legacy models were not object-oriented, the only way that data could be exchanged between the models was during periodic pauses. (Limiting data exchange between models to only certain times *does* introduce some errors into the simulation. These errors can be minimized by running the models in very small time steps, on the order of a few hours. As these legacy models are replaced with object-oriented models that can exchange data continuously, this problem will largely disappear.)
4. The models had to be able to run from a command-line input rather than an interface control input so that the simulation could be run automatically through a multiday campaign without operator action (i.e., toggling from one model to the next and manually inputting the data to be exchanged).
5. The models had to be accepted by both the warfighting and logistics communities.

The logistics model that was finally selected was ELIST (the Enhanced Logistics Intra-Theater Support Tool), developed by the Military Transportation Management Command/Transportation Engineering Agency for operational logistics. ELIST is basically a flow model that takes the elements of the TPFDD and moves them forward, using transportation resources, to their final destination. Damage to the logistics infrastructure results in delivery delays as well as bottlenecks and backlogs at logistics nodes. ELIST also allows some key parameters to be varied during the simulation pauses. These parameters, which include APOD and SPOD throughputs as well as transportation link capacities, allow the impact of successful enemy attacks against portions of the logistics infrastructure to be reflected in the simulation.

The campaign-level warfighting model chosen was Thunder, developed under the guidance of the Air Force Studies and Analysis Agency. Thunder models the air war as a stochastic simulation and includes a ground war component based on the Composite Engagement Model developed by the Army Concepts Analysis Agency. It also models the tactical logistics portion of the simulation, carrying equipment and supplies from the final TPFDD destination areas to the ground units and the forward air bases.

Linking ELIST and Thunder

One key linking problem is the difference in data detail between ELIST and Thunder. The logistics environment is detail-rich, with a TPFDD typically containing thousands of entries for all types of supplies, equipment, and personnel flowing into a theater. As mentioned, the TPFDD also includes detailed schedule and routing data. Typically, a fighter squadron might be described in the TPFDD by 50 to 100 separate unit line number (ULN) items, representing the fighter aircraft, repair crews, weapons, spare fuel tanks, military police, meteorological teams, etc. Detailed schedule and routing information on each ULN item is listed in the TPFDD, and all of this information is required in order for the squadron to be fully operational.

In contrast, campaign-level warfighting models typically have a much higher level of abstraction for warfighting units. For example, a warfighting model might represent the same squadron in terms of only a few basic descriptors, such as the numbers of aircraft and quantities of weapons and fuel.

The approach to connecting the warfighting and the logistics models was based on the force module section of the TPFDD, which lists all the ULN items that make up a specific force module like a fighter squadron. The basic process is illustrated in Figs. 2 and 3. The TPFDD is used to drive ELIST, effectively assuming that everything arrives at the SPOD or APOD as scheduled in the TPFDD. ELIST then transports these items forward to a final destination specified in the TPFDD. In calculating the transportation flow, ELIST breaks up each ULN item into a mixture of 17 commodity classes:

Air transportable tonnage
Aircraft tonnage
Ammo containerized
Ammo not containerized
Ammo tonnage
Containerized
Floating craft
Hazardous containerized
Hazardous not containerized
HET (heavy equipment transporter) movable tonnage
NAT (not air transportable) tonnage
Not containerized
Organic tonnage
Personnel
POL (petroleum, oil, and lubricants) bulk
Unidentified level 2 tonnage
Unidentified level 3/4 tonnage

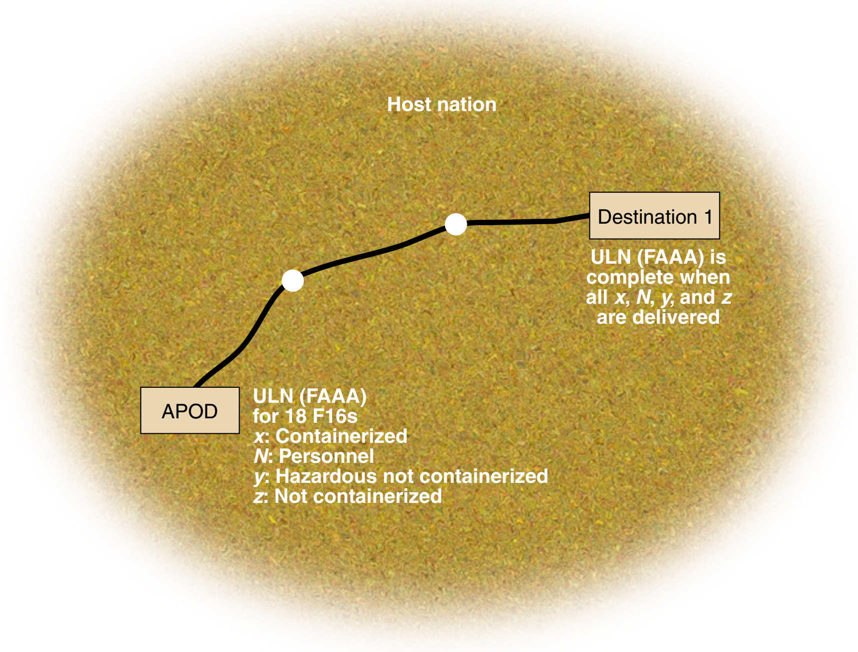

Figure 2. The ELIST transportation methodology breaks up each unit line number (ULN) item into a mixture of 17 commodity classes. In this example, there are four commodity classes for the ULN (FAAA) 18 F16s. These data (x, N, y, z) represent the TPFDD input.

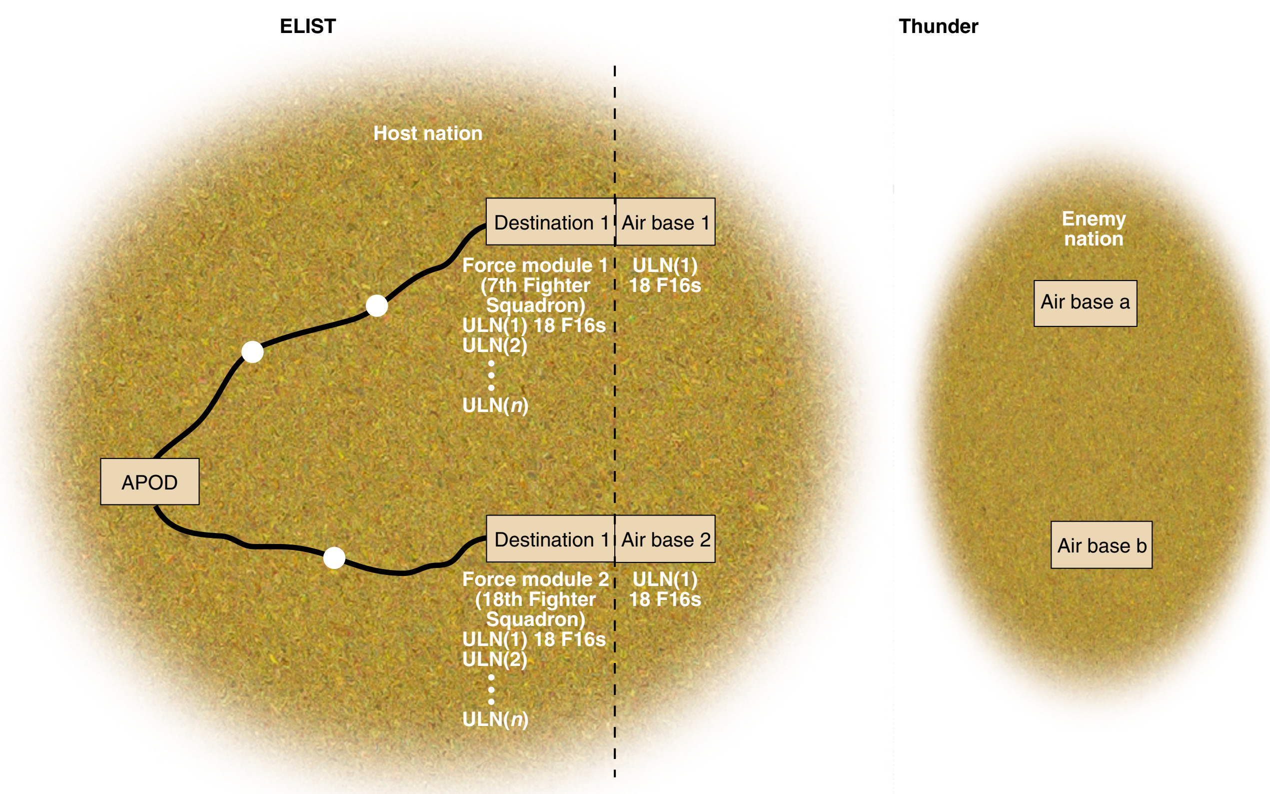

Figure 3. Thunder–ELIST linkage.

A particular ULN item may only have a few of these 17 possible classes. For example, the ULN in Fig. 2 (FAAA), representing the 18 F16 fighters in a fighter squadron, consists of 4 of the 17 classes. In addition to these fighters, which fly directly to the air base, ELIST has to transport some quantity of "containerized" materiel, some number of "personnel," and quantities of "hazardous not containerized" and "not containerized" material. When all personnel have arrived and all materiel have been delivered, the ULN is considered complete. A similar procedure is used for nonunit supplies such as fuel and water.

Figure 3 illustrates the second step for the basic force module linkage. Each force module in the TPFDD represents a fighting unit such as the 7th Fighter Squadron. This squadron might have 30 separate ULN items, the first of which is the ULN labeled FAAA in Fig. 2. Again, all of these ULN items must arrive at the destination for the squadron to be fully operational, with all service kits, etc. Each ULN is considered complete following the procedure shown in Fig. 2. When all ULN items making up that force module are complete, the fighter squadron can be transferred from the destination in ELIST to the air base in Thunder and put into action. A similar procedure is followed for each force module in the TPFDD.

WLTAE HLA FEDERATION

An HLA federation is the group of models linked together in the simulation. As part of developing an HLA federation, a Federation Object Model (FOM) is required. A FOM basically describes the objects and their attributes and the interactions among members of the federation. These members, called federates, are simply the separate models in the HLA simulation. Since the WLTAE prototype was a proof-of-principle demonstration that legacy warfighting and logistics models could be dynamically linked in an HLA federation, it was not considered essential to use a complete FOM for warfighting and logistics. Figure 4 shows the objects and attributes that were used in the initial WLTAE federation.

The WLTAE federation consists of three federates.[3] Two of these federates, Thunder and ELIST, are "wrappered" with "ambassadors" that handle the conversion from the internal model variables to the objects and interactions that have been identified in the FOM. The Thunder ambassador also converts the arrival of equipment and supplies delivered by ELIST into a deployable fighting unit, using the methodology described in Figs. 2 and 3. The third federate is the WLTAE viewer/controller, which was developed to provide an integrated display environment for warfighting and logistics information, provide data logging for the WLTAE federation, and serve as an analysis tool. The viewer/controller also allows the user the option to take control of the simulation. Normally the simulation is controlled by interactions between the Thunder and ELIST federates, with the TPFDD providing the time series flow of supplies and equipment. In this mode, the viewer/controller primarily serves as a display tool, showing the location and status

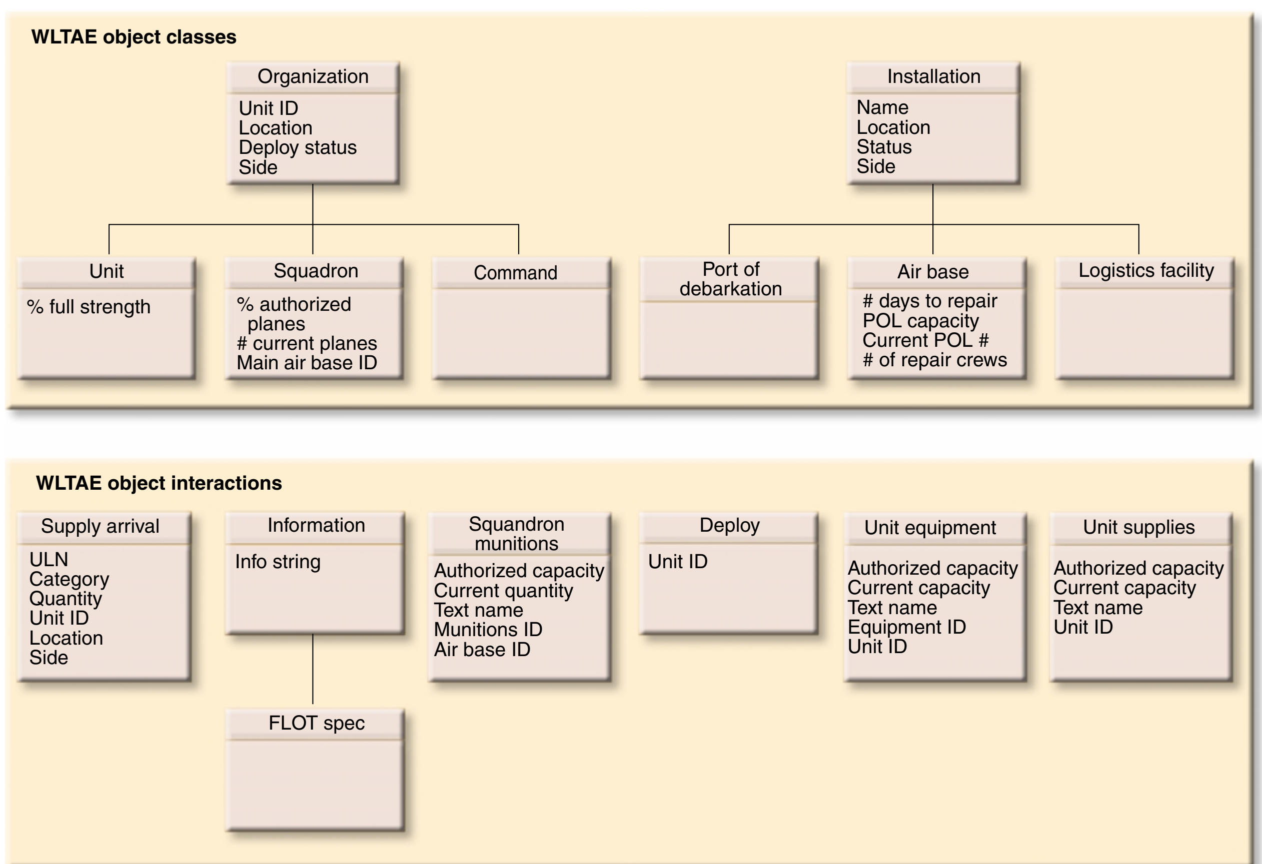

Figure 4. WLTAE Federation Object Model (POL = petroleum, oil, and lubricants; FLOT = forward line of troops).

of the various fighting units, the logistics infrastructure, and the location of the dividing line between the U.S./allied and enemy ground forces.

A typical screen for the viewer/controller is shown in Fig. 5. The viewer/controller is basically written as a Windows application and is quite easy to operate. As long as the battle is proceeding satisfactorily, according to the original plan, the user can simply view its progress on the viewer/controller screen. Figure 5 shows the locations of U.S./allied and enemy ground units.

In this particular simulation, the scenario begins with the buildup of U.S. forces in the area, about 55 days before fighting commences. During this buildup phase, personnel, equipment, and supplies flow into the country and are assembled into fighting units at various assembly areas, following the schedule and destinations given in the TPFDD. Until ELIST has delivered all the ULNs for a particular unit to its final assembly area, the unit is not considered combat ready. After all the ULNs have arrived, the unit is considered combat ready and it is transferred to Thunder to be used in the warfighting. In this particular simulation, the enemy units and U.S. coalition partners are considered fully equipped and ready to fight; they are not built up from equipment and supplies flowing into the theater. However, they are resupplied by the tactical logistics component of Thunder. If TPFDD-like data were available on coalition and enemy forces, these units could also be built up. A line running across the theater in Fig. 5 represents the forward line of troops (FLOT) and divides the enemy ground forces from the U.S./allied ground forces. The

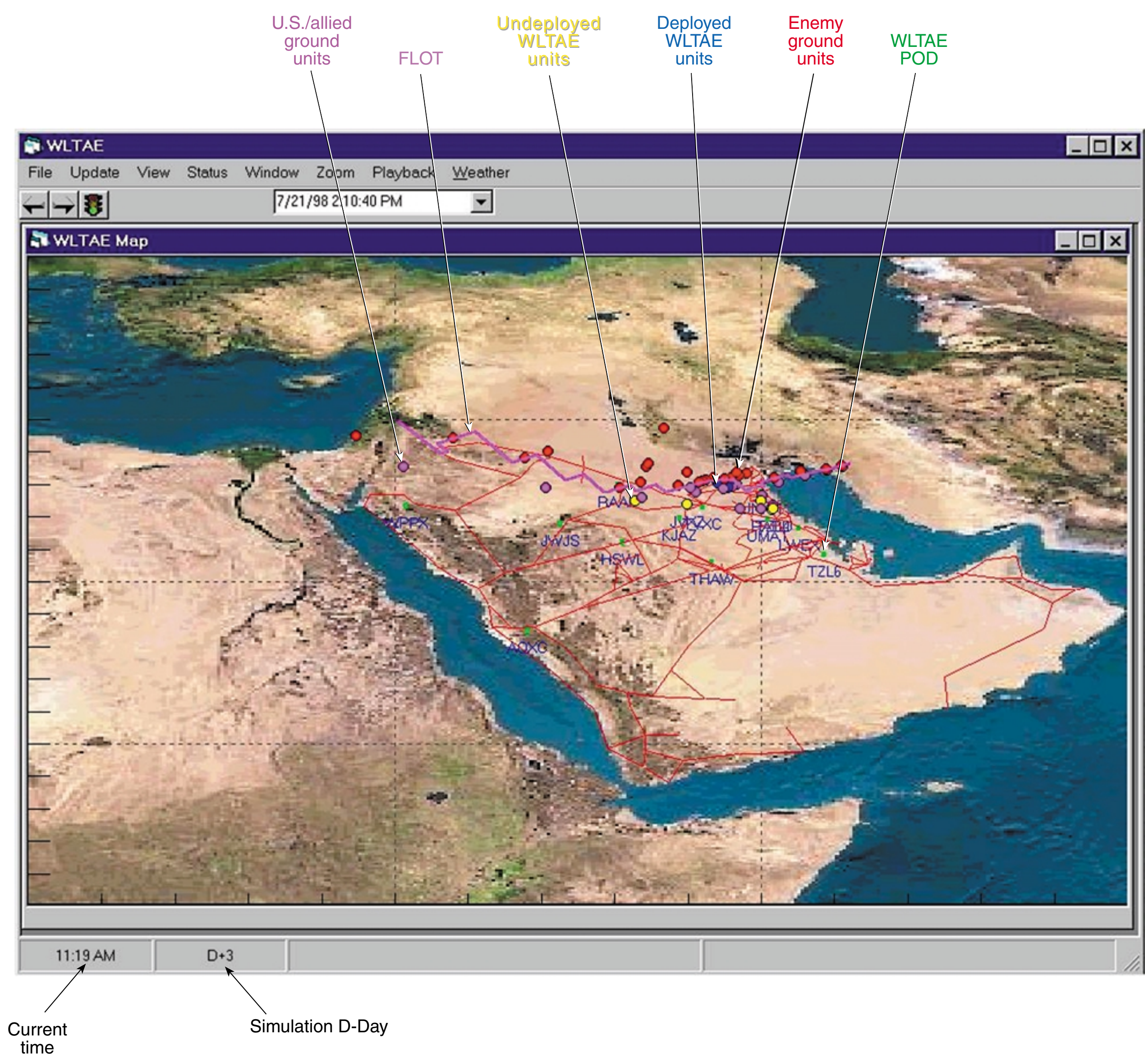

Figure 5. Typical WLTAE top-level view. (Air bases are not shown in the figure but are included in the simulation.)

movement of the FLOT is one of the key indicators that show how the ground war is progressing.

The user can also halt the simulation at any time to explore in depth the status of units and the progress of the battle. To halt the simulation, the user clicks the small stoplight in the upper left-hand portion of the screen (Fig. 6). The simulation then halts at the end of the current time step. At that point, the user can click on any of the U.S. units to drill down to determine their status and, if not deployed, determine what components are still missing. If the enemy is advancing and the user considers the unit combat ready, even though it may still be missing some of the supplies, the user can choose to force it to deploy, putting it into the simulation to fight.

Figure 6 shows the three levels of drill-down available to the user. The first level, the upper left window in the display, shows which of the 17 commodity classes need to be delivered by ELIST in order for that unit to deploy, with red text showing which commodity classes are incomplete. Clicking on any of these incomplete classes produces the middle window, which shows all the ULN items that have materiel to be transported by ELIST falling into that commodity class. Again, red indicates items not yet delivered. If the user decides the missing items are not combat critical, the "Deploy Unit" button can be clicked and the unit will go into action during the next time step. The third level, shown in the right window, looks at whether other, similar ULNs might already be nearby in the theater. These similar items can be identified because they have the same Unit Type Code (UTC). Depending on the cause of the delay and the status of these other units, the user may want to transfer the needed equipment from one unit to another. Currently, the code necessary to make these changes in the TPFDD and generate the new shipments in ELIST has not been incorporated into the simulation.

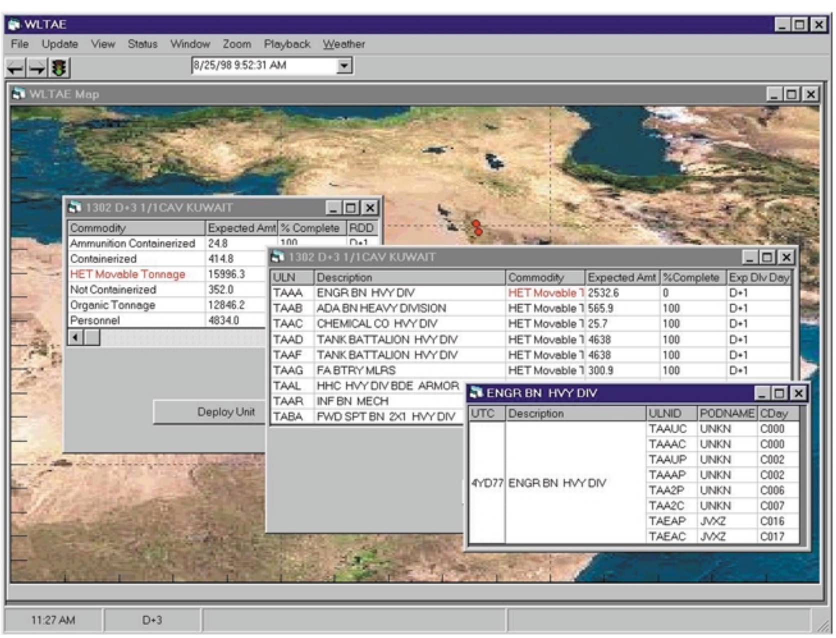

Figure 6. WLTAE viewer drill-down screens. The upper left window shows which commodity classes need to be delivered by ELIST in order for that unit to deploy, with red text showing which commodity classes are incomplete. The middle window shows all the ULN items that have materiel to be transported by ELIST falling into that commodity class. Again, red indicates items not yet delivered. The third level, shown in the right window, looks at whether other similar ULNs might already be nearby in the theater.

Status of WLTAE

The Laboratory has tested the basic WLTAE federation. The viewer/controller was installed on a PC running Windows 95 operating over a 16-Mbits token-ring network. The ELIST and Thunder federates were installed on a separate 10-Mbits Ethernet network connected by a network bridge to the token-ring network segment. The HLA run-time interface and federation executives were also run on Sun Sparc stations.

A key requirement for a fully dynamic warfighting/logistics simulation is the capability to change the TPFDD to reflect the progress of the battle. Since ELIST was originally designed as a transportation feasibility-testing model, changing the TPFDD while ELIST was running was not a requirement. Consequently, the version of ELIST used in WLTAE loads the entire TPFDD at initialization and delivers all supplies to their originally planned destinations, regardless of whether they are still needed there or whether the enemy has overrun that destination.

During 1998, we showed that it was possible to parse the TPFDD into daily batches and load this parsed TPFDD into ELIST a day at a time as "additional arrivals" during the simulation. We demonstrated that this day-by-day operating mode gave essentially the same results with ELIST as the normal mode of loading the entire TPFDD at initialization. However, the new operating mode gives the flexibility to change the TPFDD during the simulation, emulating what actually happens in real life. It is possible to redirect the remaining portions of the TPFDD to send equipment and supplies to new places where they are needed, stop delivering supplies to nodes that have been overrun by the enemy, and change the priority of shipments depending on the urgency of the battle.

A modified version of ELIST that allows this flexibility from command line mode has been provided by Argonne National Laboratories and tested at APL, but it is not currently incorporated in the WLTAE federation.

Possible Extensions

The WLTAE effort has shown that logistics and warfighting models can be dynamically linked to provide more realistic simulations of warfighting and logistics and the interactions between them. This dynamic linkage has used the HLA, making WLTAE extensible to future warfighting and logistics models. The use of the WLTAE viewer/controller in this HLA environment makes it easy to follow the progress of the simulation, to halt it at any time for in-depth assessment, and to pose a variety of "what if" questions. The HLA environment also makes it much easier to incorporate additional models into the federation, such as detailed port damage models that take weapon impact locations from Thunder and more accurately calculate the impact on port capacity.

Building on these basic capabilities, WLTAE can be further developed, for example, as a tool for the Commander-in-Chief planning staff. In this mode, WLTAE would allow the planning staff to assess several alternative courses of action in terms of factors such as logistics supportability and warfighting outcome. They could also explore the implications of enemy attacks against the in-theater logistics infrastructure such as the ports, airfields, and major transportation links. The view/controller can easily be extended to accept a wide variety of user interactions, including redirecting portions of the TPFDD as needed and modifying portions of the warfighting plans in Thunder.

WLTAE can also be developed as a tool to explore the importance of critical infrastructure protection in the United States and abroad on the ability of the military to carry out its missions overseas. Figure 7 shows a warfighting environment that may be developing, with terrorists and other state-sponsored parties attacking critical infrastructure within the United States. With the move toward lean logistics, and with supplies and equipment being moved rapidly forward from CONUS to overseas sites, the enemy could exploit a whole new set of vulnerabilities. For example the enemy could attack the telecommunications systems from the overseas theaters back to CONUS, affecting our ability to rapidly order needed supplies and equipment as well as our ability to monitor the flow of those orders. Or the transportation links and factories and warehouses within CONUS could be attacked, thus slowing the flow of supplies to the air and sea ports of embarkation.

These issues can be examined with a dynamically linked warfighting/logistics simulation that covers the operating space shown in Fig. 7. Discussions have been held with Argonne National Laboratories about linking their Distributed Intelligent Agents for Logistics (DIAL) model with WLTAE to address such questions. These linked models would provide an end-to-end logistics/warfighting simulation, a concept which has been termed the Comprehensive Logistics and Warfighting System (CLAWS).[4]

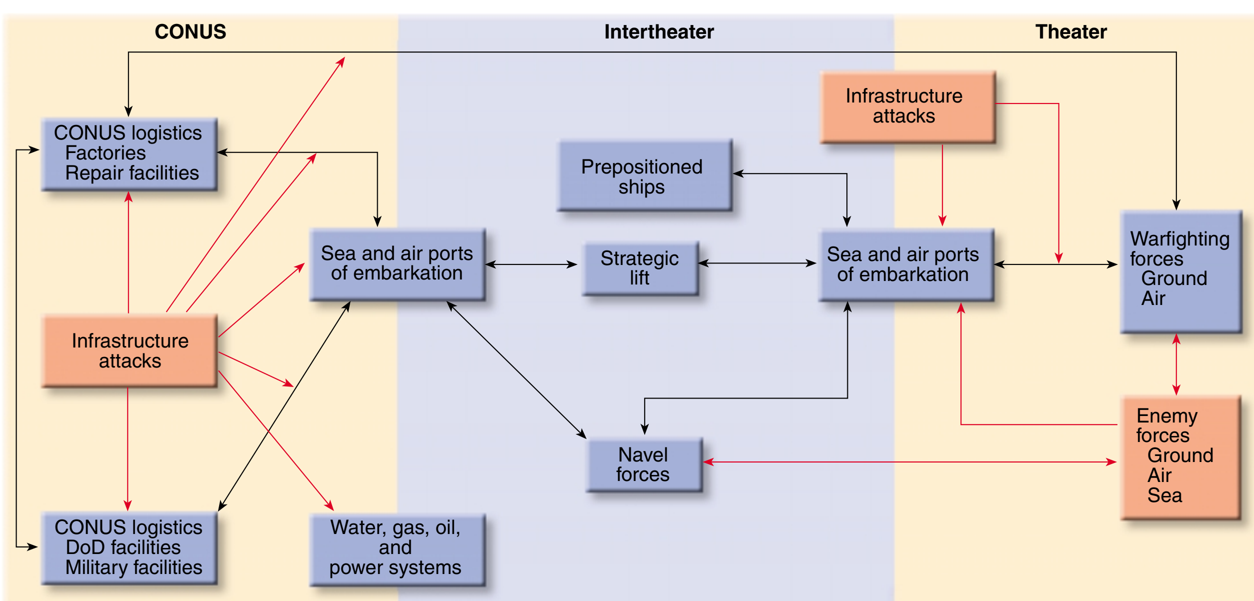

Figure 7. Applications of WLTAE to infrastructure attacks. (Black arrows show transportation and communications links; red arrows show warfighting links.)

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ACKNOWLEDGMENTS: The development of this WLTAE HLA prototype was funded in 1998 under the DARPA Advanced Logistics Program. We would like to thank the Program Manager, Todd Carrico, for his support of this effort to flexibly integrate warfighting and logistics models. The initial proof-of-principle demonstration that legacy warfighting and logistics models could be dynamically linked was supported in 1997 by the Deputy Under Secretary of Defense (Logistics) and the Joint Chiefs of Staff Director for Logistics (J4). We would also like to thank the Military Transportation Management Command-Transportation Engineering Agency for making ELIST available and the Air Force Studies and Analysis Agency for making Thunder available to the WLTAE Project.

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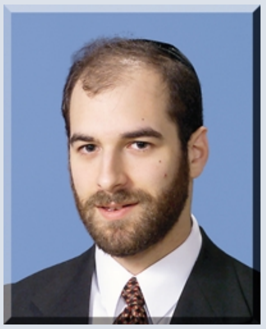

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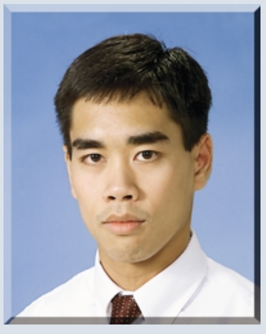

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