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# ELIST (the Enhanced Logistics Intra-Theater Support Tool), A Tool for Analyzing Theater Movement Constraints

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AI Topic: Knowledge Based Systems and Object Oriented Systems

Domain Area: Military Logistics / Deployment Planning

Languages: Applications Interface Engine, C, Prolog

Status: System developed and installed at two military installations. Supported two training exercises by providing simulation support.

Impact: Allow military planners to evaluate their current deployment plans as well as the theater infra-structure capabilities for supporting these plans.

Abstract: ELIST was conceived to allow for the detailed analysis of logistical deployment plans while simplifying the initial data entry and reducing the time required for a complete analysis. ELIST allows users to build hierarchical theater infra-structure networks (airports, seaports, road, rail, pipeline) using a graphical interface, perform discrete event simulations of deployment plans ("scenarios") which are developed on standard military planning systems, and analyze the results using textual, tabular, and graphical output at various levels of detail.

# 1 INTRODUCTION

This paper describes the Enhanced Logistics Intra-theater Support Tool (ELIST). ELIST was conceived to allow for the detailed analysis of logistical deployment plans while simplifying the initial data entry and reducing the time required for a complete analysis. ELIST allows users to build hierarchical theater infra-structure networks (airports, seaports, road, rail, pipeline) using a graphical interface, perform discrete event simulations of deployment plans ("scenarios") which are developed on standard military planning systems, and analyze the results using textual, tabular, and graphical output at various levels of detail.

This tool uses various artificial intelligence (AI) techniques. The network representation is object based, the discrete event simulation uses many heuristics, and the reports are designed in layers of resolution to assist the user in identifying problems with the current scenario.

ELIST is in use at two Department of Defense installations and has been successfully used in two exercises, providing realistic feedback to the training audiences based on their decisions.

Various languages are used in the development of ELIST. The network database has been developed using Quintus Prolog, the discrete event simulation has been written in C, and the user interface has been developed using the Application Interface Engine, an object oriented user interface design language. While these development tools are very different in nature, each was chosen to do specific functions, which they do very well.

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The following sections will describe the network building and analysis functions, the scenario structure, the discrete event simulation, the evaluation of the simulation results, and provide some conclusions.

# 2 NETWORK

The ELIST network representation is object based. It has been our experience that though many people claim to have a complete set of data for their infra-structure, this is usually not the case. Regardless, there must be an easy way to input, update, and keep consistent this database. An object database with inheritance and demons was chosen to assist in these tasks.

This section will describe the class hierarchy, the instances attached to the classes, and the functions available for ensuring consistency within the network.

## 2.1 The Class Hierarchy

The class hierarchy has three types of network objects: nodes, links, and features. The three types of network objects interact in the following way. Nodes are defined as points at a specific location (i.e. geographical coordinates.) Links are defined as connecting two nodes. Features are defined at a specific location and can be attached to nodes or links. Each network object can have a complete tree of sub-classes. For example, Figure 1, "Link Class Hierarchy," shows some possible sub-classes of links.

Classes are used to define the types of network objects that exist. Each class has attributes associated with it. Each attribute is defined by: a name, a type (integer, number, binary, string, or choice), default units (none, or one of many dealing with weight, distance, volume, or rates), optional constraints (e.g. >= 0 or that it must occur within a list of values),

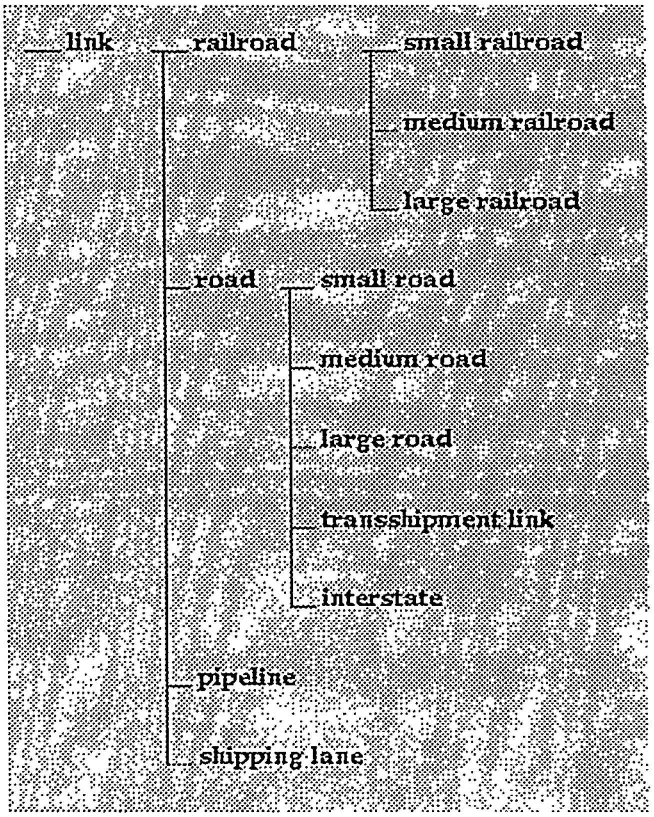


**FIGURE 1. Link Class Hierarchy**

and a default value. Each sub-class then inherits the attributes of the parent object, unless the attributes are overridden in the sub-class definition.

Attributes can also have demons (calculation routines) attached to them. Each attribute can be identified to be input to a demon and/or receive output from a demon. Each attribute that is an input, is a trigger. This implies that whenever the attribute value is modified, it will trigger the demon to execute and calculate a new value for the attribute that receives the output. This assists in maintaining a consistent database. For instance, when the capacity of a berth at a sea port is increased, the demon will trigger and calculate the capacity of the port as a whole.

## 2.2 The Instances

Instances make up the infra-structure network over which the simulation will run. Each instance in the network must be attached to a class. No input is required by the attributes of the instance. In this case, default values would all be inherited. This concept allows the user to quickly generate a base network with which to perform initial analysis. The user can then fill it in with more detail at a later time.

The recommended method for building a network is to:

1. Create the appropriate classes for the network. A complete set of network classes and attribute values is provided. Additional classes may be needed and each default values should be verified to ensure it is correct for the network that is being built. For example, these classes would include what types of airports, seaports, roads, bridges, and tunnels exist.
2. Import or create a base set of nodes. Importing the nodes assures that the nodes will match the ones associated with the scenarios that will be imported later.
3. Create links for all of the major routes.
4. Fill in the network with the rest of the detail.

The benefits to this approach are many. These include: (1) The user is able to quickly develop a network for any part of the world. (2) While the network may not be complete (not every data element correct and verified), the simulation will not stop because a data element is not known. These data elements would be inherited from the classes. (3) The more information that is added, the better the analysis will be.

## 2.3 Network Functions Available

Various network functions are available to assist the user in creating, checking, and modifying the network. A complete user interface has been incorporated for entering and updating information about the network. See Figure 2, "Instance Edit Window," for an example. The origin of each data element specifies where the data came from (Defined, Inherited, or Calculated). Any item labelled "Defined" was entered for the object through the interface. Each item labelled "Inherited" was inherited from its class. Each item labelled "Calculated" was calculated from other attributes (and possibly other instances) by the system. The date this data was entered or calculated is also displayed.

The units for each attribute are also changeable by the user. This allows the user to enter the data in the format in which it was received. For example, the user may have the length of road segments provided in kilometers. The user may enter the data using kilometers and the simulation will then automatically convert them to miles (which is what the simulation is based on.)

The user is also able to display the network on various types of maps at different scales. See Figure 3, "Viewing a Network on a Map." The user is able to create new maps using the World Data Bank II vector database, or the user is able to load and display any of the Arc Digitized Raster Graphics (ADRG) images distributed by the Defense Mapping Agency (DMA) on CD-ROMs. These provide images scaled from 1:5,000,000 to 1:50,000 on which the maps can be displayed. Functions are also being developed to plot the network over elevation data (e.g. Digital Terrain Elevation Data (DTED) also from DMA). Our experience has been that when networks from other systems (that do not have mapping capabilities) have been translated and read into ELIST, they contain many obvious errors, such as cities in the middle of an ocean, or roads that cross barriers such as rivers and oceans where no bridges exist. The user is also able to query and update the network using the map interface. Similarly, various simulation outputs can be displayed on the map. For example, theater infra-structure bottlenecks can be highlighted.

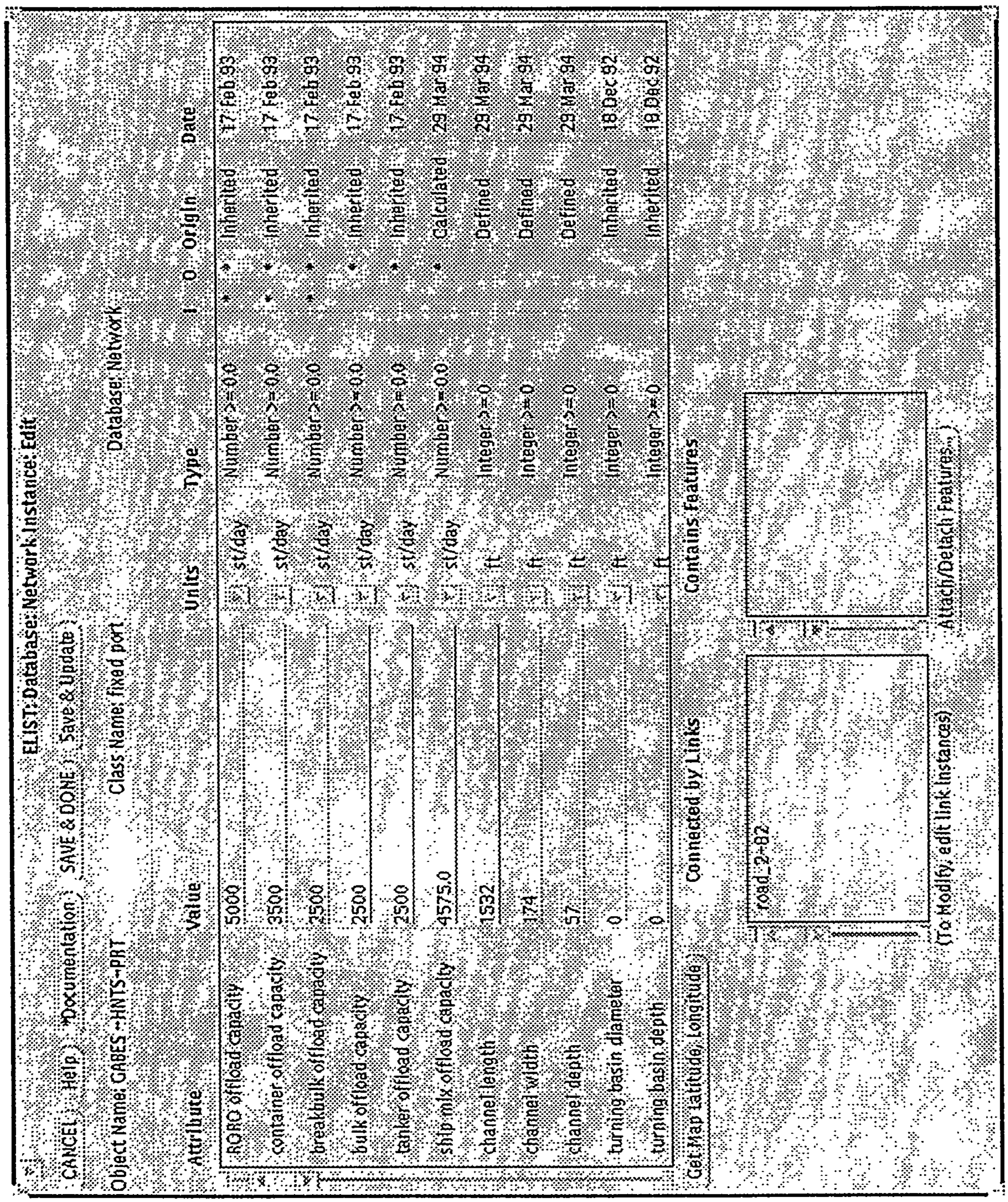


**FIGURE 2. Instance Edit Window**

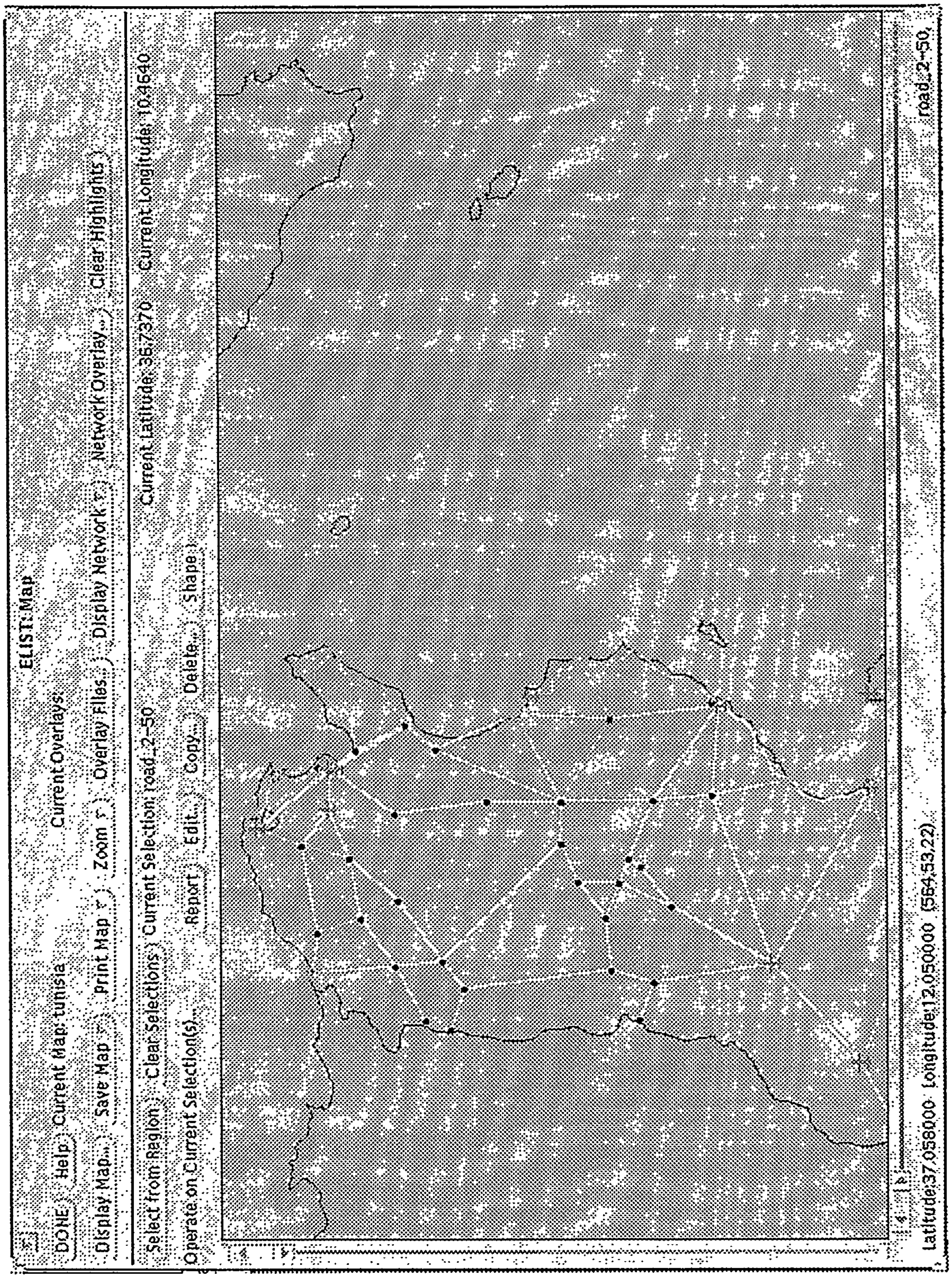


**FIGURE 3. Viewing a Network on a Map**

A query interface exists to help locate objects in the network. This function performs string matches with the instance names. Each match may be specified as case-sensitive, case-insensitive, sounds like, or most similar and be performed on either strings, substrings, begin strings, or end strings. For example, if the user did not know how to spell a city's name, but knows it begins with GAB, this could be queried. The system would then provide a complete list of locations that match this pattern.

Finally, there are functions that performs data statistics and consistency checking. These provide the user with additional tools for understanding and maintaining the networks. A report can be produced describing: how many seaports exist, how many airports exist, how many nodes of each class exist, and how many roads/rail/pipeline are connected to each class.

Another report performs integrity checking. For example, is the length of each link is within a reasonable ratio of the great circle distance between the end points? Is the database internally consistent? (e.g. Does each attribute have a default value? Does each link connect valid nodes?) Are the units of each attribute of the correct type?

# 3 SCENARIO

The scenario definition does not use AI concepts, but this paper would be incomplete without a brief overview. The scenario is based on two items, the movement requirements and the assets available to move them.

Each movement requirement specifies an amount of cargo that arrives on a vessel (air or sea) at a given port. It then specifies zero or more locations this cargo must be moved to, and when it is required at its final destination.

The assets are defined for the simulation in terms of the type asset it is, what part of the world it can serve, and what its movement capability is in terms of short-ton-miles per day. For example, an asset definition could be for medium trucks that serve the seaports on the eastern coast of a country and have a total capability 81,000 st-miles per day (45 operable trucks each carrying 10 st making two 90 mile round trips.)

When the scenario is being read, the system finds paths from each origin and destination pair specified in the movement requirements. This is done using Dijkstra's shortest-path algorithm, based on shortest travel time. The user then is able to query, update, and modify the routes using both menus and the map interface. These functions provide the abilities to (1) eliminate certain links or nodes as candidates in the path searching algorithm, (2) use different criteria, such as greatest capacity, shortest distance in the path selection, or (3) force the algorithm to use a pre-defined main supply route. The system will alert the user if an origin or destination is missing from the network, or if no path can be found.

# 4 SIMULATION

The system performs a discrete event simulation of the entire theater deployment beginning with the arrival of strategic aircraft and ships, their off-loading at their ports of debarkation (POD's), and the shipment forward to the final destination using road, rail, rotary wing aircraft, intra-theater (fixed wing) aircraft, intra-theater sealift, and pipeline.

The simulation has been designed with various distinct knowledge areas which are combined to provide an overall movement structure. For instance, there is a module devoted to off-loading vessels at seaports, a module devoted to off-loading aircraft at airports, a module devoted to queueing equipment for future movement, and a module devoted to selecting and scheduling movement across the network.

The heuristics for each of these knowledge areas has been carefully researched by reading military field manuals dealing with the subjects and performing interview sessions with experts in each of the fields. The network classes (attributes and demons) for each of the object types were then defined to capture the heuristics for determining the capability of the network objects (e.g., ports and links). The simulation was then created to use the capability numbers generated by each of the network objects in performing a flow.

Using this approach, the system is now able to perform a realistic simulation of a deployment. While this is being performed, large amounts of data are being captured for the user to be able to query and analyze

## 5 SCENARIO EVALUATION

ELIST contains a robust set of reports and graphs to assist the user in doing a complete scenario evaluation. ELIST allows the user to view the analysis of the simulation from many perspectives. An example would be helpful at this point. A common series of reports that could be requested would be:

- Overall Closure: What were my requirements compared to my capabilities? See Figure 4, "Closure Graph." This can be performed for all of the requirements, for all requirements going to a specific destination, for all units of a specific type, for a specific unit (and all of its subordinates), etc.
- Movement History: Where were items at a specific point in time (e.g., not yet arrived at the port, off-loading at the port, waiting to move forward, in transit, arrived at destination). Graphing this information in color allows the user to quickly identify major areas of concern.

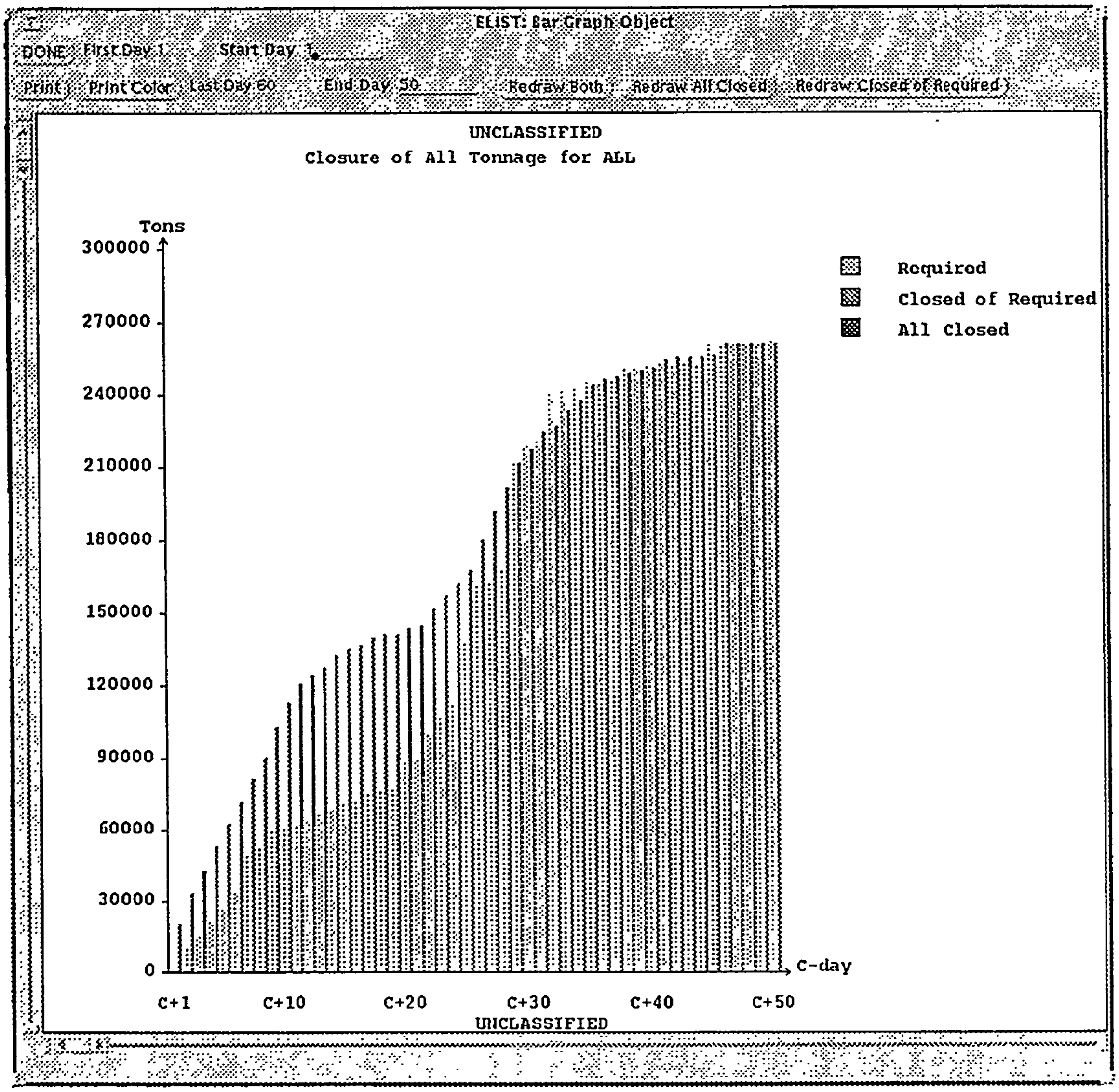


FIGURE 4. Closure Graph

- Specific Requirement Closure: Did a specific movement requirement arrive on or before its required delivery date? See Figure 5, "Requirement Closure Report." A complete history of how each requirement was moved can also be generated. This will give a complete history for each requirement including (1) when it arrived at the theater, (2) when it off-loaded, (3) when it arrived at each intermediate location, and (4) when it arrived at its final destination.
- Movement Constraints: Report which assets, nodes, and links were used at full capacity. These are ordered by those that are most constrained.
- Asset Usage: For each type of movement asset noted in the Movement Constraint report, show its usage profile (e.g., how many short ton miles / day are available versus how many were used.)

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*ELIST Summary Closure by ULNs Report*
*Scenario: 11113*
*Arrivals: 11113-dart-new*
*Simulated to Day: C+100*

*Tue Mar 29 15:13:02 1994*

**Closure at Final Destination between C+25 and C+40 for ARMY with ULN matching ***

| ULN | Description | Amount PAX | Amount Cargo (ST) | Amount POL (CBBL) | Destination | RDD | ADD | Status |
|---|---|---|---|---|---|---|---|---|
| J3BB | FA BATTALION MLRS | 397.0 | 4659.8 | 0.0 | OSAN AB-SMYU-MAP | 20 | 25 | LATE CLOSED |
| K14B | INF BN (DRF-5) | 535.0 | 213.3 | 0.0 | KIMPO INTL-MEQH-IAP | 22 | 25 | LATE CLOSED |
| K13K | FAST FOLLOW 2 | 62.0 | 497.6 | 0.0 | KIMPO INTL-MEQH-IAP | 22 | 25 | LATE CLOSED |
| J3AG | AVN MAINT CO I CORPS AC | 310.0 | 1166.4 | 0.0 | KIMPO INTL-MEQH-IAP | 23 | 25 | LATE CLOSED |
| J3AH | ENGR COMBAT BN HEAVY | 694.0 | 4597.2 | 0.0 | KIMPO INTL-MEQH-IAP | 23 | 26 | LATE CLOSED |
| J3AJ | BATTALION HEADQUARTERS | 25.0 | 23.8 | 0.0 | KIMPO INTL-MEQH-IAP | 23 | 26 | LATE CLOSED |
| J3AK | TRANS HEAVY WATERCRAFT CO | 145.0 | 130.0 | 0.0 | KIMPO INTL-MEQH-IAP | 23 | 25 | LATE CLOSED |
| 9ATE | 0083 EN DET DET FFTG FIRE T | 6.0 | 2.2 | 0.0 | EL BORMA-FTZH-APT | 24 | 25 | LATE CLOSED |
| 9ATH | 0308EN REAL ESTATE305530H6HC1 | 16.0 | 15.1 | 0.0 | EL BORMA-FTZH-APT | 24 | 25 | LATE CLOSED |
| 9ATFC | UTILITIES 4000 TEAM | 0.0 | 133.6 | 0.0 | EL BORMA-FTZH-APT | 24 | 25 | LATE CLOSED |
| 9ATJC | ENGR TOPO CO CORPS | 0 0 | 559 9 | 0.0 | EL BORMA-FTZH-APT | 24 | 25 | LATE CLOSED |
| J3AL | TRANS LIGHT MDM TRUCK CO | 135.0 | 1922.8 | 0.0 | KIMPO INTL-MEQH-IAP | 24 | 28 | LATE CLOSED |
| J3AM | QM SUPPLY CO | 143.0 | 1060.2 | 0.0 | KIMPO INTL-MEQH-IAP | 24 | 27 | LATE CLOSED |
| J3AN | MEDIUM HELICOPTER COMPANY | 123.0 | 521.0 | 0.0 | KIMPO INTL-MEQH-IAP | 24 | 26 | LATE CLOSED |
| J3AP | AIR AMBULANCE UH 1 | 54.0 | 68.2 | 0.0 | KIMPO INTL-MEQH-IAP | 24 | 26 | LATE CLOSED |
| J3AQ | EOD DETACHMENT | 23.0 | 44.8 | 0.0 | KIMPO INTL-MEQH-IAP | 24 | 26 | LATE CLOSED |
| J3AR | AIR TRF CONTROL CO FWD | 12.0 | 34.8 | 0.0 | KIMPO INTL-MEQH-IAP | 24 | 26 | LATE CLOSED |
| J3AS | AUG TEAM CORPS AVIM | 47.0 | 24.4 | 0.0 | KIMPO INTL-MEQH-IAP | 24 | 26 | LATE CLOSED |
| 9AU1 | 0073 MD DET SM ANIM VET SVC | 6 0 | 7.0 | 0.0 | MADANIYIN-NWXN-AFD | 24 | 25 | LATE CLOSED |
| 9AEPP | 0065AD01BTRY C IHAW144247H2202 | 130.0 | 0.0 | 0.0 | TOZEUR/NEFTA-TPAL-IAP | 24 | 25 | LATE CLOSED |
| 9AEQP | ADA BTRY, IMP HAWK MBL | 130.0 | 0.0 | 0.0 | TOZEUR/NEFTA-TPAL-IAP | 24 | 25 | LATE CLOSED |
| 9AGJP | 0021 CM CO SMK/DECON ABN/A | 30.0 | 0.0 | 0.0 | EL BORMA-FTZH-APT | 25 | 25 | |
| 9AG1P | 0073AR03ARMOR CO C 117218H3001 | 86.0 | 0.0 | 0.0 | EL BORMA-FTZH-APT | 25 | 25 | |
| 9AUCP | 0028MD COMBAT SPT 108123H0002 | 302.0 | 0.0 | 0.0 | EL BORMA-FTZH-APT | 25 | 26 | LATE CLOSED |
| 9AURP | 0155MD EPID SVC TM108620H0LD1 | 11.0 | 0.0 | 0.0 | EL BORMA-FTZH-APT | 25 | 26 | LATE CLOSED |
| 9AXKP | 0503CS MAINT NONDI129209H9002 | 199.0 | 0 0 | 0.0 | EL BORMA-FTZH-APT | 25 | 26 | LATE CLOSED |
| 8BEL | 0018HQ ABN CORPS 152002H4201 | 0 0 | 140 0 | 0.0 | EL BORMA-FTZH-APT | 25 | 2 | |
| 9AGJC | 0021 CM CO SMK/DECON ABN/A | 0.0 | 96.4 | 0.0 | EL BORMA-FTZH-APT | 25 | 26 | LATE CLOSED |
| 9AG1C | 0073 AR BN 03 ARMOR CO C | 0.0 | 343.1 | 0.0 | EL BORMA-FTZH-APT | 25 | 26 | LATE CLOSED |
| 9AURC | 0155 MD DET EPID SVC TM LD | 0.0 | 9.1 | 0.0 | EL BORMA-FTZH-APT | 25 | 28 | LATE CLOSED |
| 9AXLC | 0659 CS CO MAINT NONDIV DS | 0.0 | 676.6 | 0.0 | EL BORMA-FTZH-APT | 25 | 29 | LATE CLOSED |
| 9AX2C | 0364 CS CO SUP SVC, DS | 0.0 | 854.1 | 0.0 | EL BORMA-FTZH-APT | 25 | 29 | LATE CLOSED |
| 9AYEP | 0013 OD CO GM MAINTENANCE | 10.0 | 0.0 | 0.0 | JERBA/ZARZIS-JEAH-IAP | 25 | 26 | LATE CLOSED |
| 9AVD | 0978 MP CO | 177.0 | 127.1 | 0 0 | JERBA/ZARZIS-JEAH-IAP | 25 | 26 | LATE CLOSED |
| J3AT | MOVEMENT CONTROL | 5.0 | 4.2 | 0.0 | KIMHAE INTL-MEPJ-JAP | 25 | 25 | |
| J3AU | LAUNDRY SERVICE | 7.0 | 27.7 | 0.0 | KIMHAE INTL-MEPJ-JAP | 25 | 25 | |
| J3AV | FIELD SVC CO GS FWD | 123.0 | 243.5 | 0.0 | KIMHAE INTL-MEPJ-JAP | 25 | 25 | |
| J3AZ | HHD CORPS SUPPORT BN | 58.0 | 80.0 | 0.0 | KIMHAE INTL-MEPJ-JAP | 25 | 25 | |
| K37B | INF BN (DRF-9) | 559.0 | 219.4 | 0.0 | KIMPO INTL-MEQH-IAP | 25 | 30 | LATE CLOSED |

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**FIGURE 5. Requirement Closure Report**

- Infrastructure Usage: For each node and link noted in the Movement Constraint report, show its usage profile (e.g., capability versus how much was used.)

These reports allow the user to generate reports for many different circumstances. For instance, the Commander-In-Chief of an operation may want only summary reports, while the officer in charge of a certain supply area may want a detailed breakdown of all items arriving in his Area Of Responsibility. The different levels of aggregation reported allow an analyst to focus in on specific problem areas.

Work is continuing on analysis functions that will provide more assistance to the user by providing systematic ways of evaluating the data and providing conclusions for the user.

One of the areas of further research that is planned is to develop functionality for the system to automatically analyze the scenario, develop alternatives, re-simulate the scenario with the alternatives, and evaluate each of the alternatives to determine their impact.

# 6 CONCLUSION

ELIST has become a very effecting planning and analysis tool because it has successfully integrated various concepts from the AI and simulation fields into one program. The program performs an efficient and accurate simulation of the deployment of units and supplies through the theater. It also provides the user with an object oriented database to capture the network infra-structure quickly and efficiently. It also provides a multilevel series of reports and graphs that allows the user to identify problems.

While this model is designed to analyze a specific domain, military movement through a theater of operations, the concepts used in it are applicable across a wide range of applications. Many simulation systems would be greatly enhanced by assisting the user in the setup of the input data and in the verification that the input data are correct. So also on the output side, more tools are required to allow users to understand the volumes of information that are generated.