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A SIMULATION MODEL FOR MILITARY DEPLOYMENT

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ABSTRACT

The Deployment Planning Problem (DPP) for military units may in general be defined as the problem of planning the movement of geographically dispersed military units from their home bases to their final destinations using different transportation assets and a multimodal transportation network while obeying the constraints of a time-phased force deployment data describing the movement requirements for troops and equipment. Our main contribution is to develop a GIS-based, object-oriented, loosely-coupled, modular, platform-independent, multi-modal and medium-resolution discrete event simulation model to test the feasibility of deployment scenarios. While our simulation model is not a panacea for all, it allows creation and testing the feasibility of a given scenario under stochastic conditions and can provide insights into potential outcomes in a matter of a few hours.

1 INTRODUCTION

Nowadays, regional and asymmetric threats and the increase in worldwide terrorist activity continue to challenge the peace and stability in the world. Disasters, both natural and man-made, have placed additional demands on the international community for assistance. All of these have led almost all countries in the world to reconsider their military strategy and structure of their logistic support systems. The strategy of massing up large number of troops and equipment in regions where an attack or disaster is anticipated has been replaced by the military strategy that envisions having smaller but more agile forces stationed at certain places with the capability to deploy units, equipment, material, and supplies rapidly to contingency regions at the time they are required. During peace time, plans are made to deploy required number of troops and equipment to potential threat or disaster areas. During a time of crisis or natural disaster, it will be necessary to use these plans as they are, to modify them as necessary or to create new deployment plans in a short time. For these reasons, we have decided to develop a simulation model of military deployment with accurate transportation network infrastructure data and a medium-resolution allowing planners to develop and analyze plans in a relatively short time.

This study is implemented as part of a capability planning system being developed in the Scientific Decision Support Center of the Turkish General Staff Headquarters. Our simulation model will also be used along with a comprehensive optimization model of the DPP (Akgün and Tansel 2007), developed as part of the capability planning system mentioned above, to test the robustness of results from optimization under stochastic conditions of the simulation.

In Section 2, the relevant literature is briefly reviewed. In Section 3, the DPP is explained in detail. The simulation model of deployment problem is presented in Section 4, where conceptual and logical models are explained, and verification and validation issues (V&V) of our model are discussed. Finally, our conclusions and future work in our on-going research are presented in Section 5.

2 LITERATURE REVIEW

There exist deployment planning models and simulations with varying levels of detail and purpose. For a more comprehensive survey of military planning systems and a review of strategic mobility models supporting the defense transportation system, the interested reader is referred to Boukhtouta et al. (2004) and McKinzie and Barnes (2003) respectively. It is possible to classify military deployment models and simulations into two groups depending on their level of resolution and the purpose of use. First group includes relatively low-resolution models and simulations that may be used to model deployment of military units between theaters of operation (e.g., from

Turkey to Afghanistan) or inside a theater of operation (e.g., inside Turkey). Deployments between different theaters of operation using air and sea transportation assets are referred to as *strategic deployment*. The models most frequently used to model strategic deployments are *ADAMS, Allied Deployment and Movement System* (Heal and Garnett 2001) and *JFAST, The Joint Flow and Analysis System for Transportation* <http://www.jfast.org>. An example of simulations modeling deployment inside a theater of operation is *ELIST, The Enhanced Logistics Intra-Theater Support Tool* (Groningen et al. 2005). The second group includes higher-resolution models and simulations that may also be used to provide input to the models in the first group. Examples of these models and simulations are *TLoaDS, The Tactical Logistics Distribution System* (Krause and Parsons 1999), *ICIS, Integrated Consumable Item Support* (Gunshenan, Kratkiewicz and Cashon 1997), *PORTSIM, The Port Simulation* (Howard et al. 2004), *TRANSCAP, The Transportation Capability* (Burke, Love and Macal 2004) and *Evaluation of Army Corps Artillery Ammunition Supply System via Simulation* (Sabuncuoğlu and Utku 2002).

There seems to be a need to test the feasibility of strategic deployment scenarios and deployment plans inside a theater of operation. While our medium-resolution simulation model is not a panacea for all, it provides a realistic and quick litmus test for the applicability of existing deployment plans and allows a quick construction of contingency deployment plans.

3 PROBLEM AND SYSTEM DEFINITION

The DPP deals with the movement of many military units stationed at various locations, referred to as Areas of Responsibilities (AOR) (or sometimes as home bases), to their Tactical Assembly Areas (TAAs) (final destinations). The movement could be either an intra-theater or an inter-theater type. Intra-theater movement can be regarded as the movement of units using different modes of transportation (land, sea, air, and rail) inside a country's borders. Inter-theater movement refers to the movement of units between countries using air and sea assets (strategic deployment). Once the units reach the destination country, then other available modes of transportation can be utilized inside that country. In this context, the terms "theater" and "country" are used synonymously.

During intra-theater movement, a unit may go directly from its home base to its final destination throughout the entire journey using a single mode of transportation assets (TAs) on a given mode of transportation network that supports the movement of the TAs under consideration. It may also use in succession any of land, rail, sea, or air transportation networks and the TAs dedicated to them making mode changes as necessary along the way. However, the fewer the mode changes are at transfer points, the easier is the deployment. If a transfer is necessary, the initial movement from home bases is by ground transportation to a transfer point (a location where the movement switches from one mode of transportation to another). Main transfer points are harbors, train stations and airports. At these locations, the pax (troops) and cargo (weapon systems, material, equipment, and supplies) a unit has, collectively referred to here as *items*, are transferred from one set of TAs to another set that operate on a different network. This location is also called a Port of Embarkation (POE). The next mode change location, where the items are offloaded and loaded onto another set of TAs is called a Port of Debarkation (POD). These may be sea, rail and air POEs or PODs. Inter-theater movement differs from intra-theater movement only by its use of strategic lift (air and sea) assets to reach the next theater of operations.

At a transfer point, units are held in a *staging area* to prepare for shipment before being loaded on vessels. However, in many cases, there is not enough room at the terminal to stage the entire unit or large numbers of units scheduled to move at the same time. In such cases, a *marshaling area* is operated. Marshaling area provides a location to receive unit personnel, equipment and supplies, and prepare them for movement prior to entering the staging area. As the transport vessel (e.g. a ship, a train or an airplane) gets ready, the units are called from the marshaling area to the staging area. The two areas, staging area and marshaling area, serve much the same purpose. A staging area can be regarded as a service point, i.e. one with a certain capacity of material handling equipment and load/unload docks, and a marshalling area as a waiting/parking place. They help provide an uninterrupted flow of items through their transfer points. Staging/Marshalling areas are also operated at home bases and destinations (Akgün and Tansel 2007).

A unit is usually divided into three components (advance party, pax party, and cargo party) during deployment. Ground movement is conducted in convoys to maintain the unity of the component, and the size of the convoys may vary depending on operational/tactical objectives and limitations. The synchronization of departures of these components from their home bases and their arrival at their designated destinations is dictated by operational requirements, threat level present, availability and capacity (lanemeter, seat, volume, weight) of lift assets and the current conditions of transportation infrastructure (Akgün and Tansel 2007).

A unit will usually use its own (organic) TAs to conduct a deployment. However, for heavy lift requirements (for example tanks and artillery pieces) over long distances, TAs of other military transportation units may have to be used. In addition, outsourcing of TAs from national civilian companies or other nations' may be required depending on the distances and numbers and sizes of units involved in the deployment.

While time is of essence during a crisis, cost is of main concern during peace time. The source of TAs used affects the cost and timing issues of unit movements. For example, outsourced TAs may not be available on time and leasing costs are associated with them. In addition, unpredictable stochastic events (breakdowns, accidents, delays etc.), load/unload/idle times at home bases/destinations/transfer points need to be taken into account to determine if a so-called feasible or even optimal plan of deployment may be realized in actuality.

The planning for a particular deployment contingency may take place beforehand. This is called deliberate planning when time is not a critical factor. When the time available for planning for actual deployment or employment of armed forces is short, this is called crisis action planning or time-sensitive planning where the planning process is characterized by quick response, and flexibility to adapt to changing situations. Deliberate and time-sensitive action planning can be interrelated in the sense that deliberate planning contributes to time-sensitive planning. Whether deliberate or not, each deployment plan has a TPFDD which at least includes items' transportation requirements by type and quantity, and movement data by mode, earliest times of departures from home bases, and earliest and latest times of arrivals at POEs / PODs / destinations. It divides a unit's components by transportation mode, ports of embarkation or debarkation, and movement dates.

4 THE SIMULATION MODEL

We used the Event Graph (EG) methodology developed by Schruben (1983) and improved by Sargent (1988) and Buss (2001) to represent the conceptual and logical models of our simulation. In the EG methodology, nodes represent events and directed arcs represent the scheduling relationships between events. Dashed arcs represent canceling relationships. EGs can be used to, simply and elegantly, represent any Discrete Event Simulation (DES) model.

LEGO (Listener Event Graph Object) framework is used to create components of our simulation. LEGOs (Buss and Sanchez 2002) are an extension to basic EGs which allow small models to be encapsulated in reusable modules. These modules can be treated as components of other modules. This modular structure is depicted by drawing a box or rectangle around the EG. Modules or components are linked using the listener pattern of Object Oriented Programming which enables production of larger and more complex modules. LEGOs register interest in other LEGOs and take appropriate actions when they "hear" state changes. The LEGO that is listened to is not affected and is not responsible for any actions taken. This connection is enabled by having events with same name and signature in both components. This "listener" and "listened" relationship is depicted via an arc with a reversed triangle at one end, resembling a stethoscope. The object at the end of the arc with the reversed triangle is the "listened" object as depicted in Figure 1. This loose-coupling of objects in the simulation allows a great amount of flexibility. EGs and LEGOs can be programmed using *Simkit*, a Java Application Programming Interface (API) developed at the Naval Postgraduate School and freely available via <http://diana.nps.edu/Simkit/> . The listener pattern implementation in Simkit is called Simulation Event Listener or "SimEventListener" pattern using Simkit's interface name (Buss 2002, Buss and Sanchez 2002). Simkit, utilizing the same ideas of listener patterns, also uses the "PropertyChangeListener" pattern for collecting statistics from a simulation model.

To satisfy the requirement for accurate animation based on real transportation network data (such as the capacities of roads, railways and bridges), our simulation model uses a state-of-the-art Java2™ based, licensed geographical information system (GIS) named GeoKIT, as part of the transportation simulation developed. GeoKIT is an API for manipulating and visualizing 2D/3D raster and vector spatial data. It is written in the Java2™ programming language and provides a comprehensive set of components to embed GIS functionality into the applications. GeoKIT is open to all types of geographical data and is independent of any particular data format. It achieves high performance mapping and precise geodetic calculations, coordinate transformations and map projections. More information on GeoKIT can be found at <http://geokit.bilgigis.com>.

Our simulation model, developed using the tools briefly described above, has three main components; *Graphical User Interface (GUI)*, *network* and *model*. The *GUI* component allows, among other things, an accurate animation using real geospatial transportation infrastructure network data analyses require, point-and-click operations of route selection, adding/deleting/changing Home Bases/ Destinations/ POEs/ PODs and entities, and on-the-fly projection of the entire network from WGS 84 to UTM coordinates. The scenario information can be saved in XML format.

The *network* component allows shortest path selection in route planning. In addition, it allows the listing and selection of all routes on land and rail networks whose length (cost) is a user-specified percentage more than the shortest path's.

The model component has four components; Land, Sea, Rail and Air. Each of these has three subcomponents. There are components, or Java classes, modeling the transportation assets (e.g., trucks, ships, airplanes) of different capacities and modes. The loads of different sizes and military hardware that need to be transported (such as tanks, generators, and field artillery guns) are also modeled. Our simulation model currently has 84 Java classes, which will increase as additional features are added, and around 12000 lines of code.

The subcomponents in the *model* component are connected via LEGOs and SimEventListener frameworks.

4.1 SimEventListener Pattern for Land and Sea Components

The Land and Sea components and their subcomponents are connected as depicted in Figure 1.

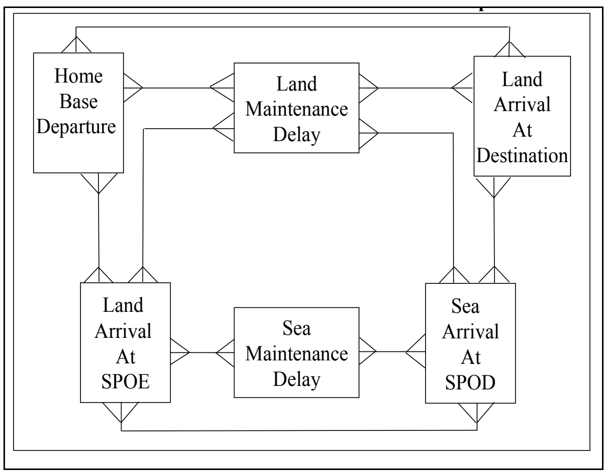

Figure 1: The SimEventListener pattern for land and sea components.

A unit departing its Home Base may directly go to its destination or arrive at a Sea Port of Embarkation (SPOE) to load its items onto a ship. After arrival by sea at a Sea Port of Debarkation (SPOD), the items will be unloaded and the unit will travel by land to its destination. Every time land transportation assets are used, maintenance delays may occur. These are modeled in the Land Maintenance Delay subcomponent. The delays due to breakdown of equipment and road traffic accidents are taken into account and the arrival time of the unit at its destination is updated accordingly. A similar situation is true for sea transportation assets departing a SPOE and arriving at a SPOD and vice versa. In order for two subcomponents to listen to each other, they both need to have events with same name and signature. The same listener pattern explained above is true for SimEventListener pattern for Land and Rail components and the SimEventListener pattern for Land and Air components.

4.2 Home Base Departure Subcomponent

Home Base Departure subcomponent simulates the loading of vehicles at their home bases, forming of convoys and their departure. The movements are conducted in convoys either to the destination or the next mode change location (transfer point) which can be a SPOE, a RPOE, or an APOE. Vehicles that do not need to make additional trips simply park at their home bases. The simplified event graph for this class is in Figure 2. Also note that the arrival events at SPOE, RPOE and APOE are omitted from this event graph to keep it simple for presentation purposes. The Run event in Figure 2 is used to schedule the first events (initial population of the event list) such as assigning movers (Trucks, Ships, Trains etc.) to their respective initial locations and also to specify earliest times of departures for the movers from their home bases. In addition, the parameters and state variables of the event graphs are not shown for sake of simplicity.

4.3 Land Maintenance Delay Subcomponent

Land Maintenance Delay subcomponent simulates possible causes of delay that may take place during the land movement of a convoy from its home base to its destination. In addition, the delays that may occur during land movement from the transfer points SPOE, APOE or RPOE, (SPOD, APOD, or RPOD) to the home base (destination) are also taken into account in the same class. The simplified event graph for this class is provided in Figure 3. The possible causes of maintenance delay are minor, medium, severe breakdowns in land transportation assets and road traffic accidents. Only minor breakdown case during travel from a home base to a destination is depicted in Figure 3.

The probabilities of breakdown are different for each type of land vehicle and they are obtained from the Turkish Army Logistics Directorate. The most probable locations of road traffic accidents are determined according to the historical data of so-called "black spots" on Turkey's roads. The data is obtained from <http://www.kgm.gov.tr/asps/trafik/karanokta.htm> and incorporated into the GIS. The probabilities of traffic accidents for these locations are obtained from a report prepared by the Turkish General Directorate of Highways for the years 1997-2002.

The simplified event graph in Figure 3 states that if a minor breakdown occurs during travel from a Home Base to a Destination, then the arrival event to destination is cancelled (the dashed arc) and after a delay time of maintenance obtained from a probability distribution, the arrival at destination is rescheduled. In a similar way, there are also possibilities of additional types of breakdown (medium and severe) and accidents when a convoy is on its way from its home base to its destination, or when it is on its way from an intermediate location such as SPOE, APOE or RPOE (SPOD, APOD, or RPOD) to its home base (destination). Certainly, there is the possibility of not having any problems while en route, and it is also incorporated into our model. Anytime land transportation assets are used, breakdowns and road traffic accidents are possible to occur. However, the events of LandArrivalAtSPOE(RPOE, APOE), LandArrivalAtSPOD(RPOD, APOD), DepartSPOE(RPOE, APOE), DepartSPOD(RPOD, APOD), DepartDestination, ArriveAtHomeBase, Medium(Major) Breakdown, RoadAccident and the canceling arcs for LandArrivalAtSPOE(RPOE,APOE), LandArrivalAtSPOD (RPOD,APOD) and ArriveAtHomeBase are omitted from Figure 3 to keep the presentation simple.

4.4 Land Arrival Destination Subcomponent

Land Arrival Destination subcomponent simulates the arrivals of convoys to their designated destination locations, unloading of the vehicles at destinations and forming of convoys and their departures to bring the remaining items of the unit (from their designated Home Bases, SPODs, RPODs or APODs) if additional trips are required. Otherwise, the vehicles park and stay at their destination locations until a next order for movement is given. If the vehicles are not carriers (e.g. tanks), they will also park and stay there upon reaching the destination. The event graph for the Land Arrival Destination subcomponent is provided in Figure 4. The VehicleArrivalAtSPOD(RPOD, APOD) events scheduled by DepartDestination event are not included in Figure 4 to keep the presentation simple.

The more complicated event graphs for subcomponents of the Sea Component (namely, Land Arrival At SPOE, Sea Maintenance Delay and Sea Arrival At SPOD) and subcomponents of Air and Rail Components are not included in this paper due to page constraints.

4.5 Animation

The implementation of animation in our simulation is performed by periodically scheduling a single recurring event called “Ping”. A component called “PingThread” simply puts “Ping” events into the event list with deterministic time between occurrences. When the “Ping” event is heard by “Simulation” subcomponent of *model* component, it updates the locations of mover objects and the “GUIMain” subcomponent of *GUI* component repaints the icons of mover objects on the map view. A screenshot of a simple implementation of this is in Figure 5. A detailed treatment of simple movement and animation in DES is presented in Buss and Sanchez (2005).

4.6 Verification and Validation

Verification and validation were conducted by using appropriate methods explained in Sargent (2001) and Balcı (1998). To mention a few more specifically, for *face validity*, we have discussed inputs and outputs of the model and its EGs with potential users of the model and personnel at Transportation Coordination Center of the General Staff. We used *assertion checking* to verify that the model functioned within its acceptable domain. Incrementally, *bottom-up testing* was performed, where each individual submodel was tested and integrated. *Fault (failure) insertion testing* was used to test whether the model responded by producing an invalid behavior given the faulty component. During *special input testing*, we used an arbitrary mixture of minimum and maximum values, and *invalid data* for the input variables, and tested for potential peculiar situations at the *boundary values*. In addition, we have tested the validity and behavior of the model under *extreme workload and congestion* at the load/unload docks and transfer points such as SPOEs, SPODs etc. Animation also helped in discovering errors during model development. Furthermore, results of the deployment optimization model developed by Akgün and Tansel (2007) were used for verification purposes. Simulation results were compared to the historical deployment data obtained from the Scientific Decision Support Center of the General Staff.

5 CONCLUSIONS AND FUTURE WORK

In this paper, we have presented our on-going work in developing a simulation model for military deployment that will help estimate whether a given plan of deployment will go as intended and determine potential problem areas. EGs and LEGOs provided a simple yet powerful and elegant way of representing DES model of deployment and enabled easy creation of component-based models of a real-life problem. We are in the process of conducting an analysis of a large scale intra-theater deployment using Latin Hypercube Sampling as described in Kleijnen et al. (2005). We plan on improving the cumbersome output and output analysis related parts of our simulation model.

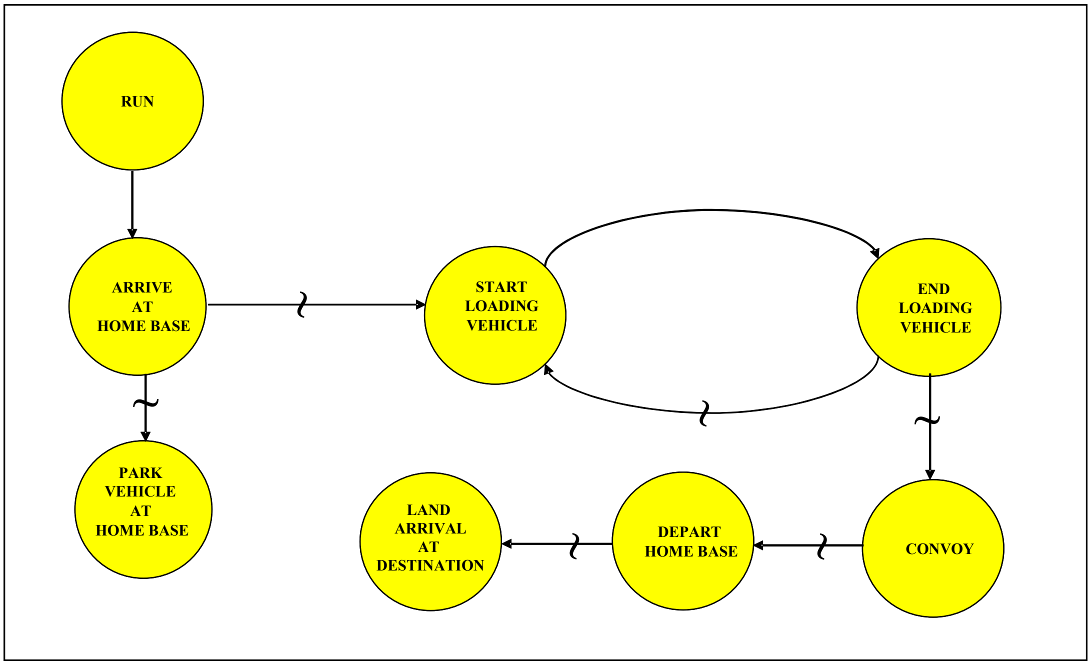

Figure 2: Home base departure subcomponent.

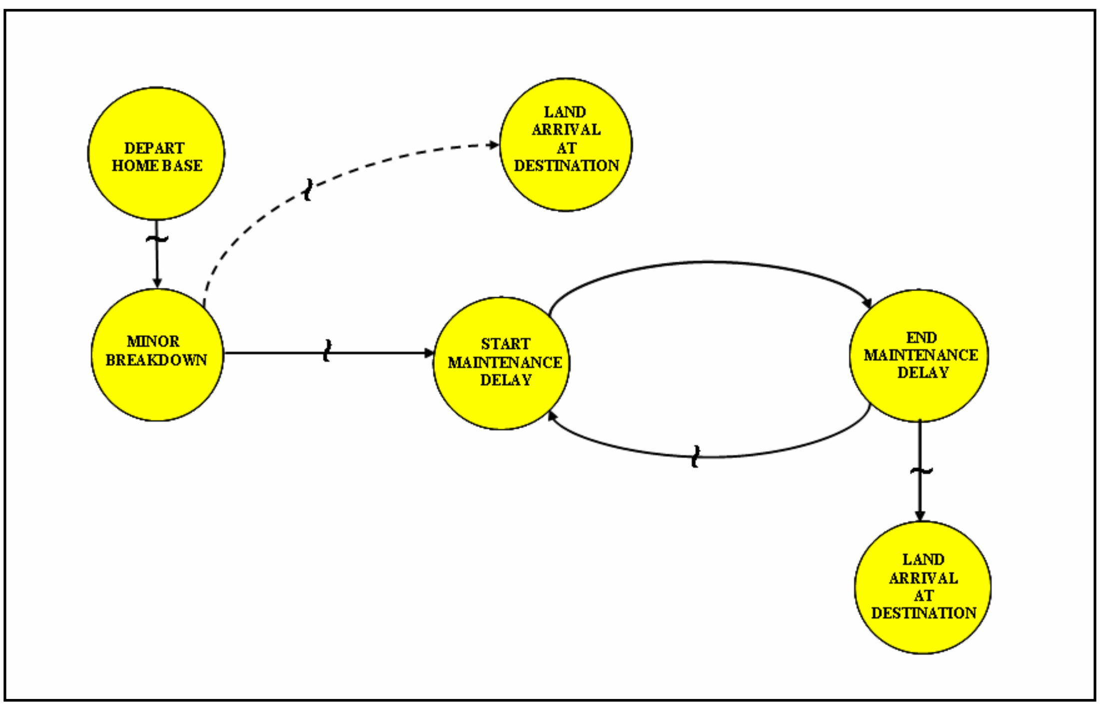

Figure 3. Land maintenance delay subcomponent.

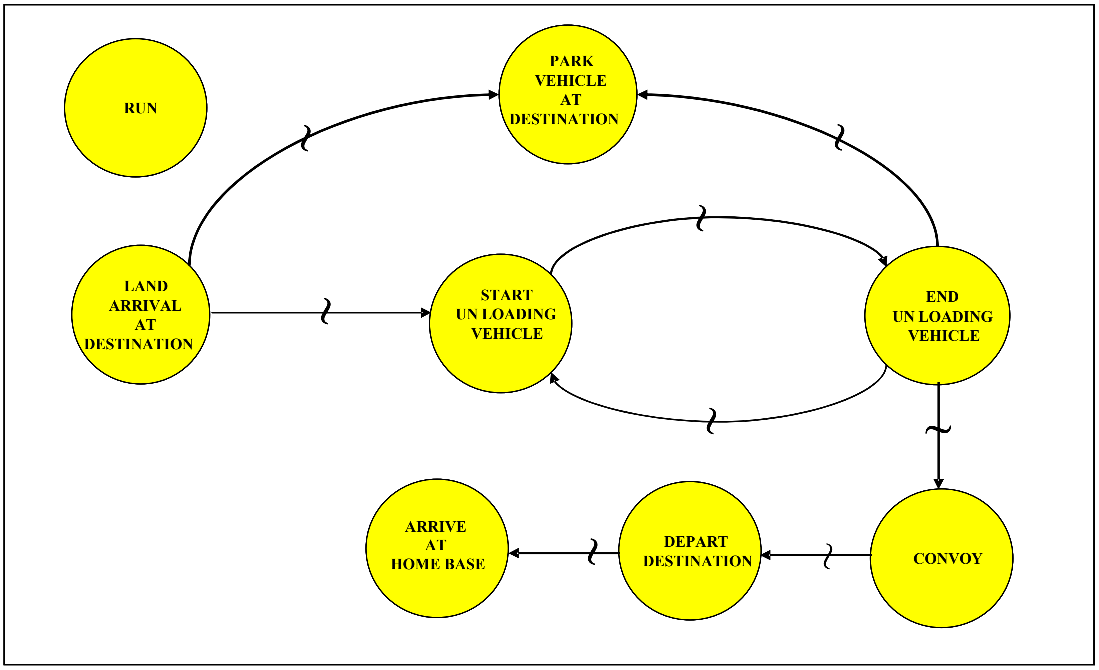

Figure 4. Land arrival destination subcomponent.

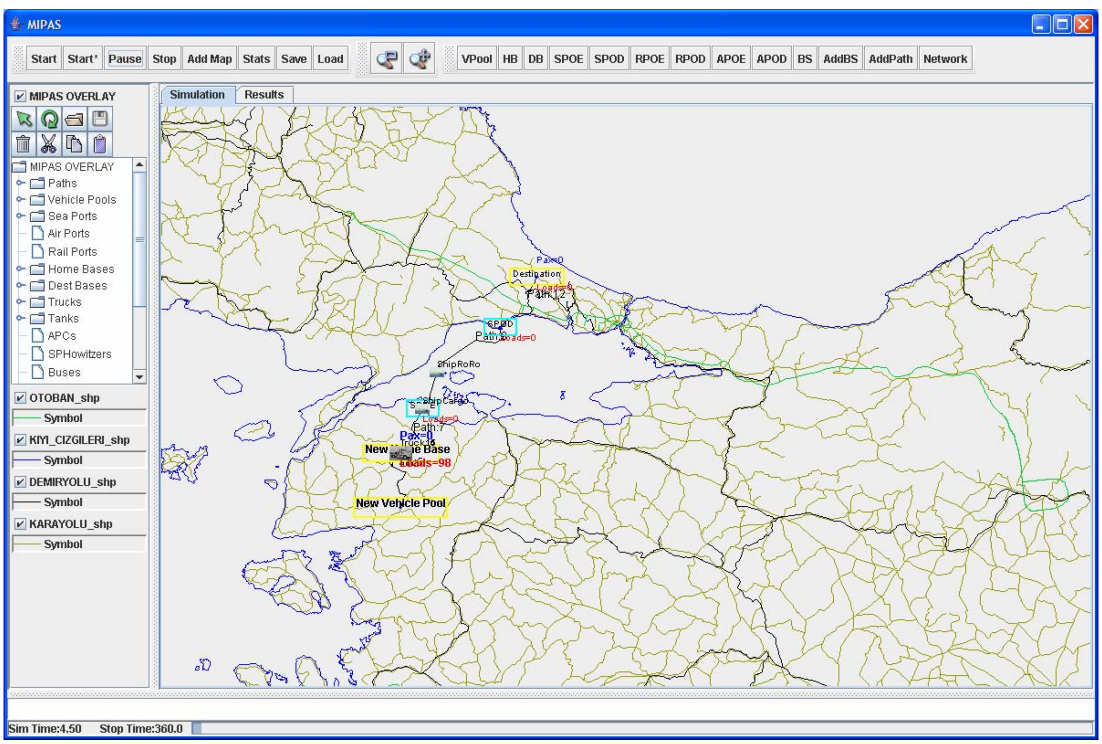

Figure 5. A screenshot of road and rail networks.

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