LG-PACKAGE: New Frontier

Boris Stilman, Vladimir Yakhnis, Oleg Umanskiy, Ron Boyd, Viacheslav Pugachev, and Lance Hagen

***Abstract*—This paper describes "new frontier" reached in the development of LG-PACKAGE, a set of the Linguistic Geometry (LG) tools, introduced first in 2004. LG is a type of game theory that generates best strategies for all sides in a conflict in real time. The paper describes the main advanced features of the versions (through Version 3.7) of LG-PACKAGE released gradually from 2004 through 2010. These releases converted LG-PACKAGE into the software of industrial strength applicable to the wide scope of defense systems. The US and British defense agencies and the world major defense contractors utilize these tools.**

***Index Terms*—Linguistic Geometry, Game Theory, Modeling and Simulation, Search Problems**

I. Introduction

LINGUISTIC Geometry (LG), a type of game theory, was first introduced in [4] in 1992. A much deeper account in LG is provided in [5]. Future directions of development of LG are considered in [10].

LG-based tools automatically generate winning strategies, tactics, and courses of action (COA) and permit the warfighter to take advantage thereof for mission planning and execution. LG looks far into the future – it is "predictive". With unmatched scalability, LG provides a faithful model of an intelligent enemy and a unified conceptual model of joint military operations. The LG tools are based on the concept of the LG *hypergame*. A hypergame is a system of several abstract board games (ABG) of various resolutions and time frames. The games are "hyper-linked", whereby a move in one of the games may (or may not) change the state of the rest of the games included in the hypergame. More details about the foundations and applications of LG are given in [3] - [10].

A set of the LG software tools, LG-PACKAGE [3], includes the following six generic components: GDK (Game Development Kit), GIK (Game Integration Kit), GRT (Game Resource Tool), GST (Game Solving Tool), GNS (Game Network Services) and GMI (Game Mobile Interface). Game construction layer includes GDK, game solving layer includes GRT and GST, game service layer that includes GIK, GNS and GMI supports both game construction and game solving.

Game Development Kit (GDK) permits creation of battlespaces, missions, and campaigns. With GDK, the analysts may optionally develop domains (Air, Ground, Joint Operations, etc.) from which specific campaigns and missions may be developed with a significant level of automation. The domain development includes modeling military hardware (UAV, manned aircraft, tanks, SAM, ships, etc.) as LG piece-templates and automatic generation of battlespace/theater templates from elevation maps in the form of DTED and shape files. Existing and future (conceptual) military systems and their concept of operations can also be modeled.

Game Integration Kit (GIK) permits integration of LG-PACKAGE into a federation of other tools, such as military C2 (Command and Control) systems (e.g., FBCB2, DCGS-A, CPOF), intelligence databases, external synthetic environments and SAF (Semi-Automated Force) simulators, control theory based tools like hybrid systems and discrete event systems, stochastic modeling tools, knowledge-based tools, etc. GIK allows LG tools to operate as a back-end to any other system – receiving all needed input data from and sending computed COA to an existing system. It further allows LG-PACKAGE to generate enhanced strategies employing access to additional information such as historical databases or real-time sensor and positional data. GIK has already been used for integration with several systems: FBCB2, JVMF, DCGS-A, OneSAF (OTB), TotalDomain, InterScope, FLAMES, JSAF, VR-Forces, and others. GIK supports a variety of communication interfaces – publish/subscribe or direct socket connections. Using GIK each LG-PACKAGE component can function as either a client or a server to provide more flexibility for integration. Both XML and binary messages are supported. The XML formats are strictly documented using XML Schema Definition (XSD) files and provide a straightforward integration method. The binary format delivers a much smaller message size and provides the greatest benefit in low bandwidth situations.

Game Resource Tool (GRT) determines the start state of the game, i.e., resources needed for a side at the start of the game in order to win. It provides an optimal (or near optimal) resource allocation for a given player (side) for every gaming template within the domain where the resources for all the

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B. Stilman is with STILMAN Advanced Strategies, 3801 E. Florida Ave., Suite 400, Denver, CO 80210 and the Department of Computer Science and Engineering, Campus Box 109, University of Colorado Denver, Denver, CO 8017-3364, USA (303-717-2110; boris@stilman-strategies.com).

V. Yakhnis is with STILMAN Advanced Strategies, 3801 E. Florida Ave., Suite 400, Denver, CO 80210, USA (vlad@stilman-strategies.com).

O. Umanskiy is with STILMAN Advanced Strategies, 3801 E. Florida Ave., Suite 400, Denver, CO 80210, USA and the Department of Computer Science and Engineering, Campus Box 109, University of Colorado Denver, Denver, CO 8017-3364, USA (oleg@stilman-strategies.com).

R. Boyd is with STILMAN Advanced Strategies, 3801 E. Florida Ave., Suite 400, Denver, CO 80210, USA (ron@stilman-strategies.com).

V. Pugachev is with STILMAN Advanced Strategies, 3801 E. Florida Ave., Suite 400, Denver, CO 80210, USA and the Department of Computer Science and Engineering, Campus Box 109, University of Colorado Denver, Denver, CO 8017-3364, USA (slava@stilman-strategies.com).

L. Hagan is with STILMAN Advanced Strategies, 3801 E. Florida Ave., Suite 400, Denver, CO 80210, USA (lance@stilman-strategies.com).

other players are already specified. While allocating resources so that the designated side may fulfill its goals with a given overall probability of success, GRT minimizes the total "opportunity cost" of the resources.

Game Solving Tool (GST) is the key component of LG-PACKAGE. It predicts and simulates the engagement beginning from the start state

- selected manually,
- received from other software tools via GIK, or
- generated by GRT.

The engagement is executed by placing and moving the pieces on the board and by automatically, in real time, making decisions for one or more sides in a conflict. GST generates the best strategies, tactics, and COA for every battlespace within the domain. To provide various levels of automation, GST can be executed in several modes, automatic, interactive, and monitoring.

Game Network Services (GNS) support automatic, parallel and distributed execution of multiple components of LG-PACKAGE over the network of computers including local high-speed networks, Internet, or combinations of both. GNS support concurrent distributed construction and execution of the large-scale LG hypergames. GNS provide extreme robustness to the LG hypergame, so that various adverse hardware/software events (anywhere in the network) would not interrupt hypergame execution. In the worst case, they may reduce execution speed.

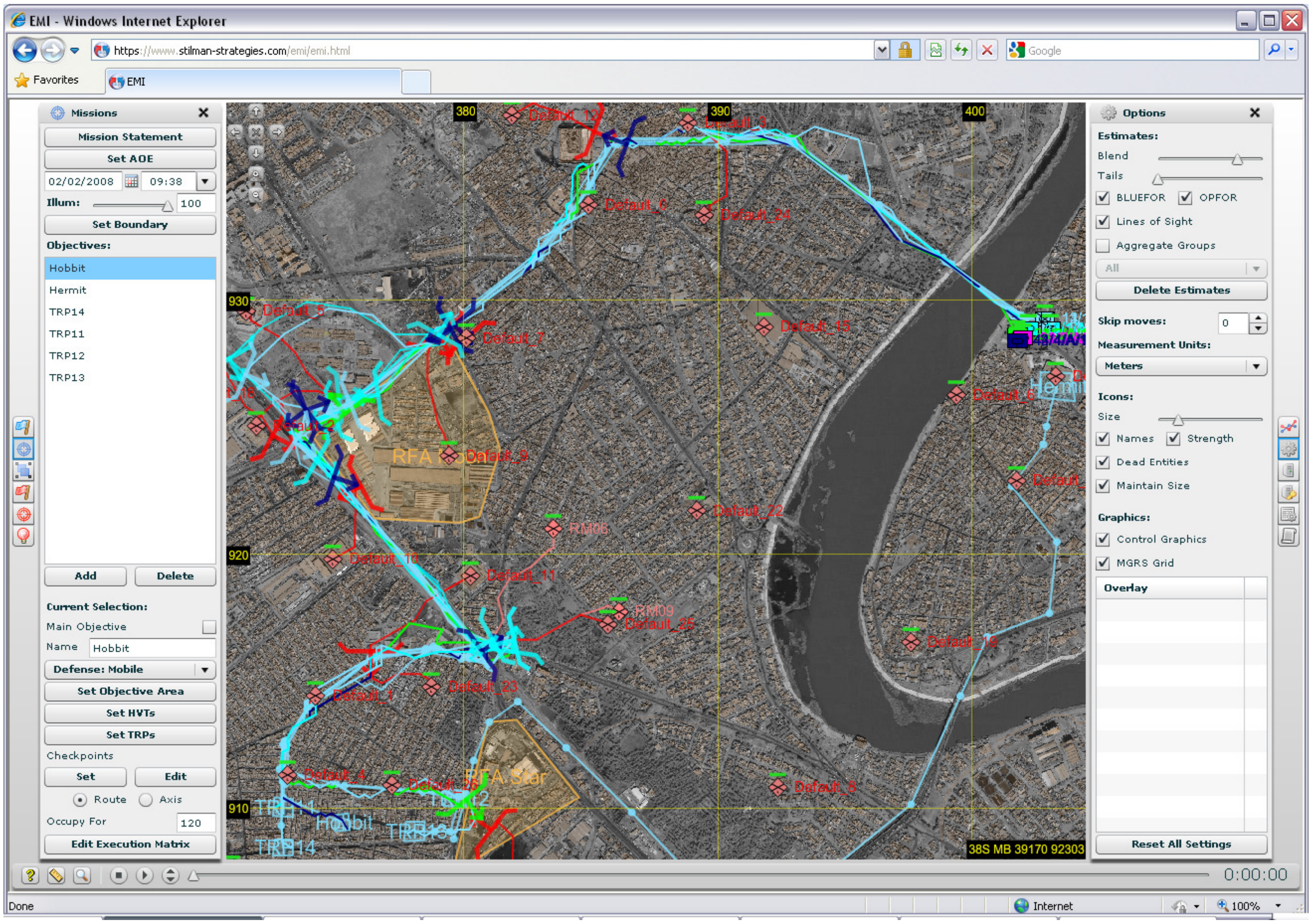
Game Mobile Interface (GMI) (Fig. 1 and Fig. 2) delivers over any network (including wireless networks and Internet) a modern, simple and task-customized interface to a particular application of LG-PACKAGE. It provides the user with an easy and natural interface to set up specific scenarios that are of the highest interest to him/her, without cluttering the interface with overwhelming options not needed for the specific intended use cases. GMI can then visualize - and let the user manipulate - the LG construction and computational components (GDK, GST, GRT and any additional data) in a similarly customized and natural manner for the desired user tasks. GMI can be executed from within any standard web browser without installing any additional software and thus makes power of LG-based COA computations easily available to any user with Internet or local network access. Different customizations of GMI include a version for touch screen computers and a different version for handheld devices such as PDAs or cell phones.

The original LG-PACKAGE, first released in 2004, consisted of just three components, GDK, GRT and GST. The subsequent major releases of LG-PACKAGE included other generic components. The basic features of all the generic components are described in [3] and [9]. In this paper we describe the advanced features that were introduced in 2004 - 2010.

II. Realistic Sensors and Communications

Realistic Sensors. LG-PACKAGE allows the user to introduce into simulation a wide range of realistic sensor types. In particular, currently simulated sensors can provide partial information about enemy objects. Depending on user-defined sensor parameters, when an enemy object comes into the detection range during a simulation, the friendly force is able to determine a combination of the following four basic parameters (or attributes) of the object: location, affiliation, type, and armament. Various settings of the parameters cover all the feasible combinations. In addition, the user can create custom sensor types. For instance, laser guidance, visual confirmation, and fire control radar could all be added as custom sensor types and later used to define guidance requirements for weapon platforms. Similarly, "Detected", "Tracked", "Recognized", and "Identified" could also be specified as custom detection types and later used to define ROE (Rules of Engagement) for missions. Using these features, the user can specify various types of guided weapons (e.g., "laser"- and "radar"-guided weapons) and their guidance sensors, as well as specify missions with restrictive ROE - such as allowing targets to be prosecuted only if they have been "identified" by an appropriate sensor. The user can specify which detection states can be reached by this sensor against each of the defined object types. For the sensors simulated by LG-PACKAGE, the user can introduce Pd (Probability of Detection) functions. This introduction can be made for each sensor-detection state-platform combination. Powerful GUI provides convenient means to easily introduce functions of any shape and complexity. For example, a sensor could be defined to provide location of certain types of enemy aircraft with Pd = 100% up to 20 km range, and slowly drop to 0% by the range of 50 km. The shape of this Pd function can easily be defined by the user. The definition of this same sensor could be extended to include the following. This sensor would be able to detect the type of enemy objects with 75% probability at 10 km range and 0% probability beyond that range. Other target types could be specified as invisible to this particular sensor.

Sophisticated Sensor and Worldview Models. LG-PACKAGE includes an sophisticated model of sensor interactions. Instead of having a Boolean parameter describing each entity, i.e., either known or not known in a particular worldview, LG-PACKAGE employs a parameter with a 'certainty' value assigned to each entity. When the entity is originally detected by someone's sensor, it is known with full certainty, which entity was detected. Then, this information decays overtime indicating that this knowledge is outdated. The speed of such decay is dictated by the properties of the entity, as its maximum speed. A subsequent sensor contact would restore the certainty back to 100%. Another concept utilized in LG-PACKAGE is called a "negative sensor contact". When a sensor is used to scan a location where the entity was last known to be, and yet it is not currently detected there, the certainty value of that entity is rapidly lowered based on the probability of detection of the sensor. The negative sensors can be used to confirm that the entity is not where it was believed to be. Furthermore, "intelligence entities" can be introduced into worldviews to improve the ability to setup scenarios with incomplete and uncertain



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Objectives:
Hobbit
Hermit
TRP14
TRP11
TRP12
TRP13

Current Selection:
Main Objective □
Name Hobbit
Defense: Mobile
Checkpoints
● Route ○ Axis
Occupy For 120

Estimates:
Blend
Tails
☑ BLUEFOR ☑ OPFOR
☑ Lines of Sight
□ Aggregate Groups
All
Skip moves: 0
Measurement Units: Meters
Icons:
Size
☑ Names ☑ Strength
☑ Dead Entities
☑ Maintain Size
Graphics:
☑ Control Graphics
☑ MGRS Grid
Overlay

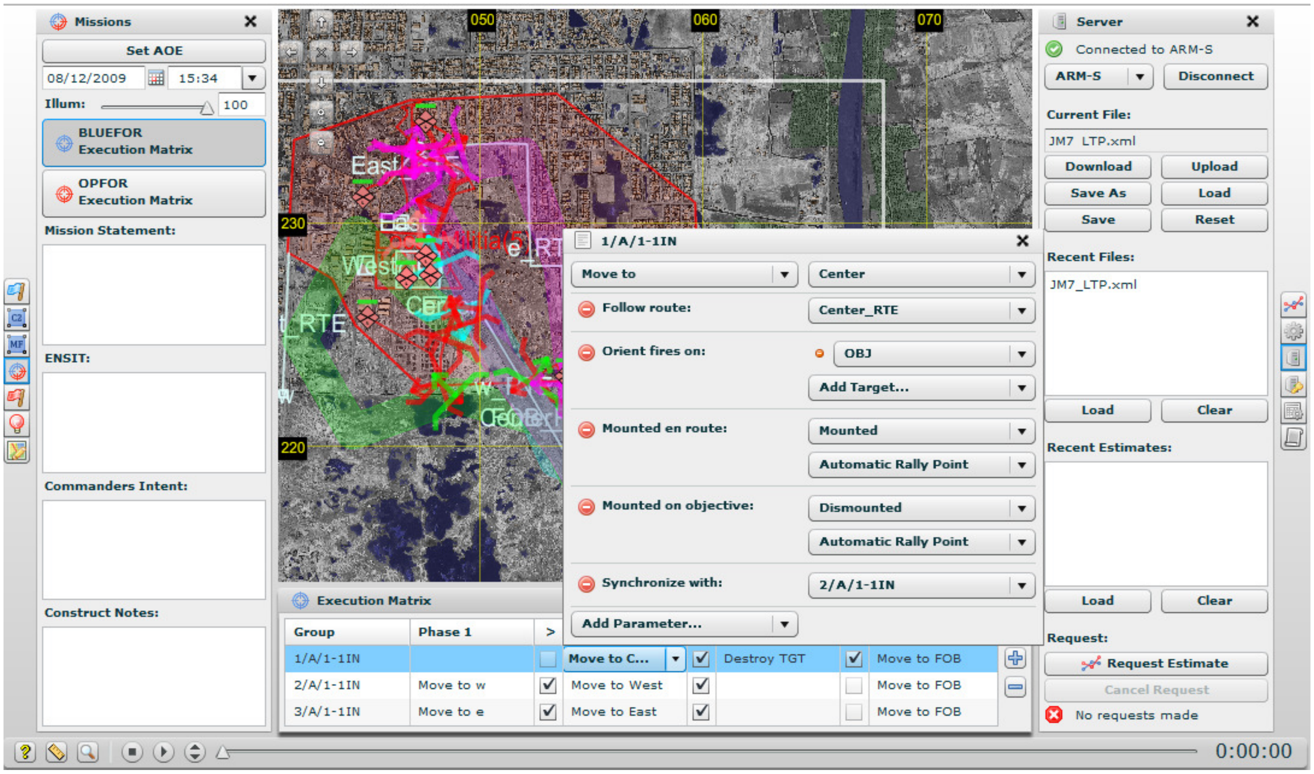
Fig. 1. GMI: Detailed COA for Blue and Red forces in complex urban terrain.

information. This permits modeling a wide range of missions and behaviors, including Search missions and Intelligence Verification missions (Section III). For instance, a UAV can be tasked to fly to all locations with intelligence pieces and verify whether there is (or is not) an actual enemy entity there employing positive or negative sensor contacts.

Realistic Communications. LG-PACKAGE allows modeling realistic "imperfect" communications. It allows the user to break down each of the conflicting sides into communication groups. Each of the communication groups maintains its own worldview and uses an independent LG Engine to generate strategies, COA and movement for all its members. The user can also define communication links and their associated delays. For each communication group, the associated LG Engine bases its reasoning only on information available within the communication group's worldview. This information is fused from the sensor inputs from all the entities of the communication group, as well as from information arriving through communication links to the other communication groups (with appropriate communication delays as applicable). In addition, LG-PACKAGE allows the user to simulate and assess the dependencies of outcomes of various engagements upon the communication infrastructures. Various communication delays between the communication groups, breakdowns of the forces into communication groups, as well as dynamic real-time changes to the communication network can be experimented with to analyze their effect on the simulation. LG-PACKAGE automatically enables the information flow from one communication group to another via the shortest path through any allowed communication links and nodes. This flow can change dynamically with changes in the communication infrastructure, e.g., if an important intermediate node is destroyed in the engagement. Furthermore, communication groups allow experimentation with the effects of appropriate command structures (Section V) upon the outcome of engagements by modeling the improved information flow stemming from an efficient command hierarchy. Finally, the GUI allows the user to visualize the worldview of each individual communication group to understand the differences in their current operational picture and their impact on the groups' decision making, i.e., computation of strategies and COA.

III. Complex Missions and Operations

Mission Editor. GST includes a highly flexible Mission Editor. Communication groups described above (Section II) can further be broken into task groups, which can be assigned missions via the Mission Editor. Each mission can be assigned to multiple task groups to be performed cooperatively or to allow LG to choose the best fitting task group for the mission. At this time, Attack, Defend, and Relocate mission types are



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Mission Statement:

ENSIT:

Commanders Intent:

Construct Notes:

1/A/1-1IN

Move to: Center

Follow route: Center_RTE

Orient fires on: OBJ

Add Target...

Mounted en route: Mounted

Automatic Rally Point

Mounted on objective: Dismounted

Automatic Rally Point

Synchronize with: 2/A/1-1IN

Add Parameter...

Execution Matrix

Group	Phase 1	>					
1/A/1-1IN		☐	Move to C...	☑	Destroy TGT	☑	Move to FOB
2/A/1-1IN	Move to w	☑	Move to West	☑		☐	Move to FOB
3/A/1-1IN	Move to e	☑	Move to East	☑		☐	Move to FOB

Connected to ARM-S

ARM-S

Current File: JM7 LTP.xml

Recent Files: JM7_LTP.xml

Recent Estimates:

Request:

No requests made

Fig. 2. GMI: Entering detailed Mission Order in Execution Matrix format modeled after US Army standard.

supported. Missions can target specific units or all units within a specific area that meet the Targeting Criteria. Such criteria can specify, which types of units can be attacked, which sides they must belong to, as well as detection states that must be attained by those units before they can be attacked. Even more complicated Rules of Engagement can be set up using Targeting Criteria based on simulation time, status of other missions, or even friendly or enemy force strengths. The Mission Editor permits employment of the logical expressions using Start, Pass, and Fail Mission Criteria. This allows the user to specify combination of events or parameters that must be met before a mission can start, be considered successful or failed. Each such criterion can be a complex logical proposition of variables that include simulation time ranges, status of other missions, friendly or enemy force strengths, etc. Force strength parameter can further be fine tuned by the user to only include certain types of units, and only the units within certain areas or groups. Missions can also include way points to be passed through on the way to the main objectives. The Mission Editor allows the user to simulate available intelligence on enemy missions by permitting reflected missions, i.e., those to be executed by one side and such that their existence is known to the other side as the other side's "intelligence".

Missions' Hierarchy. Missions in LG-PACKAGE can be organized hierarchically. A mission can contain other missions within it. Different types of such hierarchies are supported. A "sequential" mission group can be used to quickly specify several submissions that need to be executed in order. A "synchronized" mission group controls the sub-missions to be executed and finished altogether. Another type of a mission group is a "segmented" mission that is essentially a single mission that is broken down into smaller components with different actions and tasks. Such groupings facilitate creation of complex interconnected mission structures for scenarios even easier while taking advantage of other existing Mission Editor features.

Execution Matrix. The Mission Editor provides a way to define very complex and flexible mission structures (see above). However, some users require an interface that is structured differently. As part of GMI, LG-PACKAGE includes an additional mission editor, the Execution Matrix (Fig. 2). This method is based on the actual US Army method for specifying mission orders which is a matrix of organization groups along one axis, and the time or mission phases along the other axis. Each cell of the matrix contains a task order that specifies what each group has to do during each phase of the mission. The task order consists of a "task-action" and a "task-target", where the target type depends on the action. For instance, an "attack" action can be applied to both an objective area and to an enemy force, while a "clear" action can only be applied to an objective area or a route. The tasks can also include additional parameters which specify "how" the task is to be done, e.g., waypoints to be followed, orientation of forces on the objective, and whether the mission is to be mounted or dismounted. The Execution Matrix approach does not allow as much flexibility as the general LG Mission Editor (see above); however, it provides an approach, which is familiar to the US Army trained personnel and covers the range of mission orders that they are required to execute. Due to its simplicity, Execution Matrix is also much faster to use.

Search Missions. Currently, a list of mission types includes various Area Search Missions. Such missions are defined in terms of the area to be searched, types of entities being searched for, and desired search pattern – such as "creeping line" or "square patterns". In addition, these search patterns can be automatically computed based on sensor parameters, e.g., probabilities of detection, of the search assets to achieve desired coverage for the search area. The search missions are integrated into the rest of the software functionality; they can be used in conjunction with other missions, and take full advantage of the rest of the COA generation capabilities. For example, the user can model a scenario simulating a search by UAV assets for hostile air defense resources, followed by a more thorough search executed by manned aircraft with fighter escort for high value targets, with the escorts responding to any threats to the search assets, culminating with a time critical targeting (TCT) missions to destroy any discovered high value targets.

Generic Mount/Dismount Missions. LG-PACKAGE includes the ability to model operations that involve units transitioning between mounted and dismounted actions within the same scenario. This allows modeling the following sample operations. A platoon of infantry is traveling to the target area mounted on Infantry Combat Vehicles, dismounting and attacking the enemy on foot with vehicles used for fire support, re-mounting to move to the next objective, and dismounting en-route if a threat is discovered. The system can automatically select mount rally points of several types to support TTP (Tactics, Techniques and Procedures). For instance, a single rally point can be chosen for the entire platoon to assemble and mount together or individual vehicles can pick up their passengers independently with a separate mount rally point for each vehicle. This functionality is not restricted to the Army land operations. For instance, this can be applied to modeling a battleship transporting unmanned attack submarines or other assets such as attack helicopters, deploying those submarines & helicopters in the mission area or defensively as needed, performing the attack jointly, followed by the submarines and helicopters "re-mounting" the battleship and proceeding to the next mission. This functionality can be controlled by the user by specifying desired mounted or dismounted operation for each mission, as well as defining relationships between different entities to specify possible mount options.

Support Missions. LG-PACKAGE permits constructing missions that support other missions. Such missions do not have their own target but are rather assigned to a particular different mission or a group to be supported. Such support roles include:

- "follow and support",
- "quick reaction force", and
- "support by fire".

In a "follow and support" mission, the support group will follow behind the supported group, and as needed, come forward to assist the supported group against any threats or to help attack its final target.

In a "quick reaction force", the support group will remain in its original location and, if any threat to the supported group is detected, rapidly move in to intercept such threat.

"Support by fire" is used typically when a main attack on the final objective is to be assisted by establishing a base of fire on a different axis and suppressing the enemy by direct or indirect fire during the final assault. GST can automatically calculate the appropriate location for such base of fire in a support mission.

Missions for MOUT Operations. LG-PACKAGE provides extensive support for modeling Military Operations in Urban Terrain (MOUT). This is achieved by taking advantage of the cumulative effect of all other features of LG-PACKAGE combined with some advanced functionality for modeling CONOPS (concept of operations), SOP (Standard Operating Procedures) and TTP for urban asymmetric operations. The most important features are as follows:

- Competency and aggressiveness properties that can be assigned to entities to simulate different behaviors, e.g., differentiate between militia and trained foreign fighters,
- Tactics other than direct force-on-force, such as running away, hiding behaviors, non-aggressive posturing,
- Rules of Engagement (ROE) on weapon use, such as not engaging the enemy until the enemy engages first,
- Indirect fire support weapons with complex ROE, such as the size and armament of the target, and proximity of friendly forces,
- Customizable generation of the LG zones [5]-[10] simulating different SOP and TTP, such as non-aggressive posturing, formations en-route, reserve forces, medical evacuation, and reactive defensive tactics,
- Synchronization of platoons to achieve maximum effect of overwhelming force and massing of weapon fires, and
- Maintaining cohesion of a platoon throughout the operation.

IV. Complex Terrain

Complex Terrain Modeling. LG-PACKAGE allows the user to model domains and scenarios involving complex terrain models. This includes terrain elevations, separation of land and water, and an additional layer of the terrain features data including buildings, roads, bridges, rivers, lakes, and forested areas. In addition, a notion of "density" is introduced to distinguish between cells of the game board that are completely occupied by a feature (such as building or canopies) and those that are only partially occupied by this feature. These terrain models are completely integrated into the rest of the LG algorithms. For instance, "flexible" reachability relations [5], [6] can be defined as follows. They can be different for land and for roads. In addition, we can define reachability relations that only apply on water; or those that permit faster movement when moving through forests of lower density, slower - in more dense areas, and even slower - in heavily built-up areas. We can define weapons that can only be fired at targets that are in the open rather than those taking cover in buildings or heavily forested areas. We can define sensors that have different levels of penetration depending on what is encountered along the line of sight from the sensor to the target – whether it is small buildings, lighter or heavier forested areas. This permits a variety of locations and domains to be modeled realistically, e.g., littoral operations, ground operations in rural terrain, as well as operations in urban terrain.

Terrain Analysis. LG-PACKAGE includes a customizable terrain analysis engine that can process complex terrain models including buildings, roads, rivers, lakes, bridges, and canopies. This terrain analysis engine permits to distinguish dangerous and preferred areas based on lines of sight, terrain, range of friendly and hostile weapons, current known or estimated positions of enemy forces. Such analysis can be customized employing an extensive GUI. This GUI permits to produce completely different (and tactically valid) terrain analysis for different types of entities. For instance, the analysis for dismounted troops could be configured to highlight wide open areas within range of weapon fire from built-up areas as the most dangerous, while considering locations in the buildings that are high enough to provide good lines of sight over neighboring areas as the best observation/fire positions. For vehicles, this analysis could be reversed to show that it is most dangerous for vehicles to be tight in between buildings (where they are susceptible to RPG fire), while the best positions are in open areas where the effect of long ranges of fire of their weapons is maximized. This analysis can also be used to indicate user preferences, e.g., traveling through forests or through buildings, over land or over water, high in the air or low to the ground, etc. The results of such terrain analysis are directly applied to affect calculation of COA by influencing the LG trajectories and zones being generated. Thus, all the forces are choosing the safest and most efficient routes to dominate the enemy forces.

Automated Terrain Import. LG-PACKAGE permits developing scenarios for a given geographical location by supporting several key terrain data formats. In particular, the most important formats are Digital Terrain Elevation Data (DTED), which is the most commonly used format for elevation data, as well as "shape files", which are utilized for the terrain features such as buildings, roads, rivers, lakes, and canopies. DTED and shape files are automatically translated into the internal LG-PACKAGE representation of the LG Abstract Board [3], [5]-[10]. An ability to automatically import such raw terrain information supports directly complex terrain models, terrain analysis, and MOUT operations (Section III). This ability provides a straightforward procedure for supplying terrain details for creating scenarios and domains that can take advantage of those details.

Quick Terrain Editing. For best application of the LG technology, LG-PACKAGE requires realistic terrain information containing elevation data as well as other terrain features such as buildings, roads, and rivers. Sometimes, such data is difficult to acquire for regions of interest and, in other cases, this data is outdated or of lower quality. While professional tools exist to build and update such databases, they are extremely expensive and can be difficult to use. LG-PACKAGE includes a component for editing terrain features to allow for quick modifications or construction of terrain databases directly from the GMI. This gives the GMI users an ability to perform calculations to quickly adjust the terrain source data in case of discrepancies with the real terrain they have noticed.

V. Sophisticated Simulations

Command Hierarchy. LG-PACKAGE allows the user to define aggregation of entities into the higher level virtual entities, the LG pieces [5], [6], as part of a command hierarchy. For example, individual tank entities of a platoon can be aggregated into the platoon entity (or unit), several of which can in turn be aggregated into the company entities. The GUI allows the user to visualize the current situation at any level of aggregation. In presence of the entities of various levels, the overall strategy/COA calculations are always performed by LG at the best level of resolution available in the hypergame, as defined by the user. This is especially useful if a multi-resolution LG hypergame is utilized because it permits to understand and assess the difference of decision making between high-level plans generated for the aggregated units, e.g., platoons, based on a low resolution map and detailed strategies generated for the finer-grain units or entities on a high resolution map. This can also be used to improve efficiency of calculations by simulating aggregated platoons when high resolution is not needed, and switching to individual entity representation during critical segments of the simulation. LG-PACKAGE allows the users to create teams, coalitions and introduce various types of collaboration within the LG hypergame.

Complex Pieces and Engagements. LG-PACKAGE supports a variety of simulation scenarios. For example, attrition and strength based scenarios are supported in addition to the standard Pk (Probability of Kill) based scenarios. This allows the user to define simulation where a single virtual entity, an LG piece, represents a group of real-world physical entities by specifying the strength (and/or size) of an entity. During an engagement the strength of such piece is decremented via an attrition calculation based on the combat effectiveness of the attack unit against the target unit. When the strength of a piece drops below a user specified threshold, the entity is considered destroyed. Another class of engagements requires modeling of decreased accuracy of weapons at greater distances. LG-PACKAGE supports the user definable "probability of hit" curves for each weapon that simulate decreased accuracy at longer ranges. Other parameters allow the user modifying values of probability of kill based on the effect of suppression due to hostile fire.

Batch Mode. LG-PACKAGE supports execution of simulation scenarios in a batch mode. The user can specify several initial positions and missions of the forces as well as the number of times to run each scenario. LG-PACKAGE executes each scenario the desired number of times and outputs detailed logs for each run as well as aggregated statistics. The optional logging features allow the user to request logging of nearly every type of event in a simulation including movements, engagements, sensor contacts, and communication exchanges.

Server Based Operation. LG-PACKAGE includes a capability to be executed in a server-client deployment in addition to the standard graphical standalone application. The LG-PACKAGE components can be executed as services on a server and accessed remotely from GMI over the network. This allows for a single LG-PACKAGE installation to be accessed by multiple simultaneous users. The server side components provide file storage, user access control, queue of request and interconnections to other 3rd party systems, such as a number of deployed military systems. A configuration utility is included to simplify configuration and maintenance of the server side components.

Help System. LG-PACKAGE contains a built-in comprehensive help system. This help system can be accessed from within any of the LG-PACKAGE GUI-enabled applications, such as GDK, GST, GRT, and GMI or it can be accessed independently. The content includes instructions for operating GUI, explanations for options available to the user of each of the software components, as well as tutorials and step-by-step instructions for performing most common user operations. The help system is continuously expanded to include more information as new features are introduced into software and by request from users for more information on specific topics. This help system is about to become context-sensitive.

Advanced GUI. The feedback from engineers and military experts after utilizing earlier versions of LG-PACKAGE allowed STILMAN to significantly improve the GUI. The current GUI permits to streamline user experience and provide additional visualization and editing tools. Such improvements include an ability to overlay any images over the 2D map display, draw freehand on the 2D map display, and measure distances. All the major editors enabling LG-PACKAGE GUI, including Mission Editor, Group Manager (Communications), Table of Organization (Command Hierarchy), and Piece Properties, are based on a unified hierarchical data presentation model and are highly transparent for the user. Further extensive collaboration with military users and SMEs allowed us to develop GMI, a light, highly mobile, streamlined interface that provides the most convenient, fast, and operationally correct method to manipulate all the components of LG-PACKAGE (Section I).

VI. Real Time Response

A number of defense systems require generating long term LG-based predictions in real time or near real time. These systems include RAID (Real-time Adversarial Intelligence and Decision-making) [1], [2], [3], [8], [9], FBCB2 (Force XXI Battle Command Brigade and Below) deployed on all the US Army Assault Vehicles, CPOF (Command Post of the Future) deployed at the top echelons of the US Army Battle Command, and Striker Embedded Training System. Additionally, various constructive simulation systems, such as OneSAF, require real time execution of the LG tools if those are utilized as an intelligent driver for both Blue and Red forces. Real time performance will be a must for applying LG for intelligent control of unmanned vehicles, aerial, water and ground. Those requirements were considered for developing LTP, the major optimization procedure.

Long Term Plans (LTP). LG-PACKAGE allows the user to calculate LTP, which are “deep” plans (estimates) including tightly interconnected estimates of the hostile COA and recommendations of the friendly COA. The standard operation of LG-PACKAGE is concerned with computing the most efficient action to be done by friendly and hostile forces at any given moment, and then repeat this computation cycle after every concurrent game move. This repetition leads to regenerating all the LG constructs, the LG zones and trajectories, and each time advancing the planning “distance horizon” over the abstract board [5]-[10]. These zones and trajectories serve as “rail tracks” for movement and actions of the LG pieces. The LTP procedure adds an ability to extend this technology by advancing the board horizon (and the respective time horizon) much further during one computation cycle without a significant increase of computation time.

Instead of regenerating all the LG constructs at each planning game move, the LTP procedure reuses trajectories and zones and drives pieces along these rail tracks until the first branching, i.e., until the moment when the first choice has to be made. After the initial zones and trajectories are generated, a path is chosen for every piece just as in the standard operation. However, after making a single move for each piece along its chosen path, as long as no branching point has been reached, new paths for entities do not have to be generated. Any piece that is still moving along its initially chosen path can continue movement without any new computations needed. On the other hand, when a critical event occurs – such as an engagement, discovery of new enemy forces, or a mission change – new zones and trajectories are generated for affected pieces and new paths are chosen. LG keeps track of both directly affected pieces, e.g., those involved in the engagement, as well as indirectly affected pieces, e.g., entities that are performing a collaborative task with the directly affected pieces. This allows for minimization of the set of pieces that require new trajectories and zones while still ensuring that this set includes all the pieces that may have to branch from the current path, i.e., may need to change their behavior. Analogously to the serial ABG [5], such reuse, is called “LG Zone Translation”.

This optimization reuse permits to dramatically reduce the multi-move computation cycle down to 1-3 min while a standard one-move computation cycle requires 0.5-1 min. Specifically, the LTP procedure permits computing the likely course of events over a much longer period of time, the “time horizon”, e.g., 250(!) game moves ahead, which may reflect several hours or days of astronomic time depending on the size of time interval for one move.

LTP contains all the required information about the “future”. It includes initial positions of all the friendly and hostile pieces, as well as all the gradual changes, their estimated movements and actions, over the entire desired time horizon.

While LTP is meant to provide a deep look ahead into the future, even with all the predictive power of LG, that could include large number of branches (based on the outcome of engagements – random events, decisions made by the enemy, new sensor contacts, etc.), only one such branch of events is provided in each LTP. However, multiple LTPs can be computed based on slightly different input parameters to gain a broader understanding of the expected future up to the desired time horizon. LG-PACKAGE GUI (Fig. 1) provides an ability to view such estimated COA in the animated mode to help the user get an intuitive understanding of how the future is likely to unfold. Numerous experiments and analysis by SME (Subject Matter Experts) have shown that all the generated LTP are of high quality comparable or even better than those produced by the experienced experts, [2] and [3].

The main ideas and key algorithms that led to development of LTP have been thoroughly tested within DARPA RAID and US Army SBIR Phase II projects [2], [3], [8], [9].

VII. Utilizing LG-PACKAGE

The first organization that licensed the first release of LG-PACKAGE in 2004 was Dstl (Defence Science and Technology Lab) of the Ministry of Defence of UK. Subsequently, several versions of LG-PACKAGE were licensed to BAE Systems (UK) and Boeing (USA). A number of departments at Boeing including Boeing Integration Centers (BIC East and BIC West) utilized LG-PACKAGE. Various versions of customized LG-PACKAGE were licensed to the US DoD (Department of Defense) agencies including DARPA (Defense Advanced Research Projects Agency), JFCOM (Joint Forces Command) and NSWC (Naval Surface Warfare Center). Currently, the most active users of the latest versions of LG-PACKAGE are the three US Army organizations, DCGS-A (Distributed Common Ground System – Army), FBCB2 (Force XXI Battle Command Brigade and Below) and ARL (Army Research Lab for SIPRNET). Internationally, the key organization utilizing currently a universal version of LG-PACKAGE is SELEX Galileo, (UK), a Finmeccanica Company.

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