Modeling and Simulation of Stability and Support Operations (SASO)

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Abstract

Stability and Support Operations (SASO) are becoming increasingly important in modern military operations. Conflicts are no longer comprised solely of two opposing sides engaged in combat on an open battlefield. Instead, they are more likely to involve groups sharing various alliances and relationships each pursuing a range of different goals. The Sheherazade SASO wargaming engine presented here: a) incorporates subjective criteria for scoring Course of Action (COA) success such as the animosity between factions and attitudes of locales, b) uses non-traditional units such as refugees, media and information operators, and c) employs a co-evolutionary genetic algorithm in modeling the dynamics of the complex multi-sided simulation for generating COAs. This paper outlines our approach towards the development of a wargaming model that handles the more complex and computationally demanding arena of SASO.

1. Introduction

Current wargame simulators attempt to capture the basic principles of conventional military operations and condense them into a set of abstract rules. Wargaming algorithms developed from these rules are used in carefully constructed simulation environments that allow users (commanders and battlestaff) to recreate, replay, explore and evaluate various alternative scenarios in a computer-based setting. These simulators are based on Major Theater of War (MTW) scenarios which typically involve two sides (representing friendly and enemy forces) fighting towards simple goals such as gaining territory or maximizing enemy attrition. An increasing number of operations today involve parties or forces representing more than just two conflicting groups with opposing or complementary goals. Large-scale military operations increasingly incorporate Stability and Support Operations (SASO) that take place in smaller, more specific locations, for example, within a city or other urban developments.

The purpose of stability operations is "to promote and sustain regional and global stability" and "to meet the immediate needs of designated groups, for a limited time, until civil authorities can accomplish these tasks without military assistance" [1]. Examples include UN peacekeeping operations in regions plagued by disputing warlords where a military presence is required to maintain the stability of the region.

Many wargaming systems have been designed for simulating conventional MTW operations because of its long history and the availability of vast amounts of data from historical databases that have yielded various accepted rules of combat. Stability and support operations are only beginning to be studied and analyzed in the same way. However, SASO models are inherently more complex than conventional military operations because of their multi-dimensional characteristics. Soft factors such as the attitudes of the regions involved, animosity and alliances of local factions and populations, unpredictability of spontaneous civilian incidents, etc., contribute to the evaluation of various SASO scenarios. The large number of variables involved and the unpredictability of entity interactions create a complicated environment, which does not lend itself easily to mathematical modeling.

This paper presents a simulation wargaming system that models the SASO environment. Three parts comprise the system: Sheherazade, a wargaming engine for SASO; ATACKS, a 3-Dimensional battlespace visualization platform; and the genetic algorithm-based coevolution simulation environment that encompasses Sheherazade. Section 2 of this paper discusses some of the special considerations pertaining to SASO environments that are

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incorporated into the Sheherazade wargaming model. Section 3 provides an overview of the coevolution-based simulation environment in which the wargaming model executes. Section 4 describes the SASO wargaming algorithm, Sheherazade, in detail. Section 5 presents an example scenario with output generated from the 3D visualization system, ATACKS. Finally, Section 6 concludes with a brief summary and discussion of future work.

2. SASO environment

In the Sheherazade SASO system, the environment is composed of demographic regions that represent locales or neighborhoods on a map. Entities, such as conventional military units, militias, etc. move across the various regions as specified by their plans, or courses-of-action. They also engage other entities in incidents according to these plans.

Sheherazade consults the "animosity" levels of various local, civilian populations and units of varying allegiances to determine whether an "incident," such as a riot, will spontaneously occur. Generally, the primary responsibility of the conventional military units will be to reduce the number of those incidents, which threaten the security of the nation-building or humanitarian mission, thus reducing animosity levels. Sheherazade also allows for paramilitary units, such as the warlord militias that existed in Afghanistan, or a fully organized military force like the Serbian Army. In addition to the conventional military units, a militia and terrorist unit, Sheherazade supports various new types of units such as political agitators, media, refugees, and organized crime units.

Sheherazade explicitly models the "attitudes" of the populations in each region. The attitude measures the agitated or calm state of the local populations. When the region is highly agitated, incidents are more likely to occur. Some units, such as the media units, have the ability to calm or agitate a locale. Other units, such as the military police will tend to calm attitudes. Incidents will tend to agitate and can cause a cascading effect in which incidents raise attitudes, which cause more incidents, and so on.

To set up a SASO environment, information about each of the units must be entered, as well as information about the regions, the local populations and their attitudes, and the animosities of each side for the others. A military expert wishing to setup a SASO simulation defines these basic game parameters and starting values: the number of factions and their animosities (i.e., how they initially feel about each other), the number of regions and their areas, faction population distributions, region terrain difficulty and attitude factors, and initial parameters for all the units, including footprints, strength, combat power, intel power, IO type (calming or agitating), role (support or operations), etc., as shown in Table 1 below.

Table 1 Input parameters for Units

	Conventional Military	Terrorist	Militia	Information Operator	Apolitical non-combatant
Alliance	X	X	X	X	X
IO Type(calming/agitating)	X		X	X	X
Incubation		X			
Recovery		X			
Footprint	X		X		
Initial Strength	X	X	X		
Combat power	X	X	X		
Intel power	X	X			
IO power	X	X	X	X	X
Police power	X		X		
ROE discipline	X		X		

Each of these parameters is defined as follows:

Alliance: to which faction this unit belongs

IO Type: does this unit have an agitating or calming effect on a region; the IO power determines the strength of its effect

Role: primarily for terrorists, either support or operations; a support unit does not carry out attacks but causes operations units in the same region to have less incubation times

Incubation: the time it takes the unit to set up its operations in the region

Recovery: the time it takes a unit to recover from an attack

Footprint: the area or coverage of this unit. It is divided by the area of the locale to determine the unit's effective footprint which can help increase the probability of finding terrorists, but also increase the likelihood of unplanned incidents.

Initial strength: a reflection of the starting health of the unit. Current strength begins at this value and decreases with more combat incidents

Combat power: akin to the fighting power of this unit, it influences the damages assigned to the two parties involved in an incident

Intel power: the power of this unit in helping to find terrorists

IO power: influences the attitudes of regions and amplifies the animosity increase when a

	member of this unit's faction is attacked.
Police power:	influences the attitudes of regions, generally producing a calming effect
ROE discipline:	the likelihood of the unit's violating the "rules of engagement" and causing an incident

3. System overview

This section briefly describes the steps required to setup and run a Sheherazade simulation environment. As shown in Figure 1, a genetic algorithm is used to generate and evolve courses-of-actions or COAs that are evaluated by the Sheherazade wargamer. Each COA specifies the movements and targets of each unit. To begin the cycle, a randomly generated starting COA is supplied to the SASO wargamer. The wargamer runs the COA over the specified number of cycles and returns the final averaged values (scores) of the simulation. These scores are used as part of a fitness function. The genetic algorithm uses the fitness function to select good COAs, and from those generates new COAs that are run again in the SASO simulation. In other words, a fitness score for the COA is calculated based on the fitness function criteria and the genetic algorithm continues to evolve future generations of COAs based on the results. Because each side, or faction, has a turn evaluating and generating COAs, these COAs are said to "co-evolve."

Because the focus of this paper is the SASO simulation, the discussion of the details of the genetic algorithm-based coevolution algorithm is left for a previous publication, see [3]. In terms of this discussion, we assume that a SASO simulation is given a set of COAs which determines the force distributions, movements and targets of the various units.

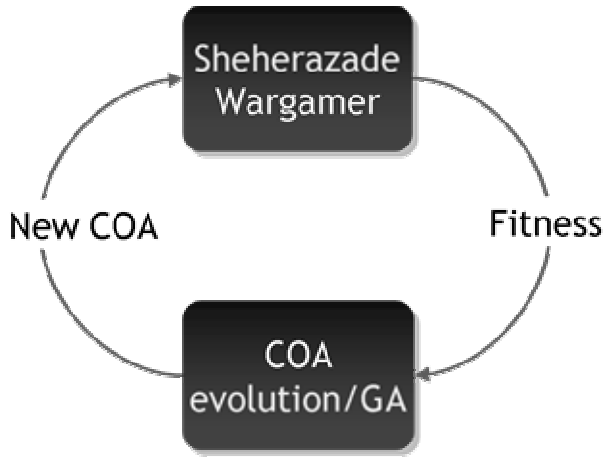

Figure 1. Coevolution of COAs using Sheherazade

For all units except conventional military force structure units (infantry, military intelligence, military police), the COA consists of movements and the time schedule for the movements. A simulation consists of

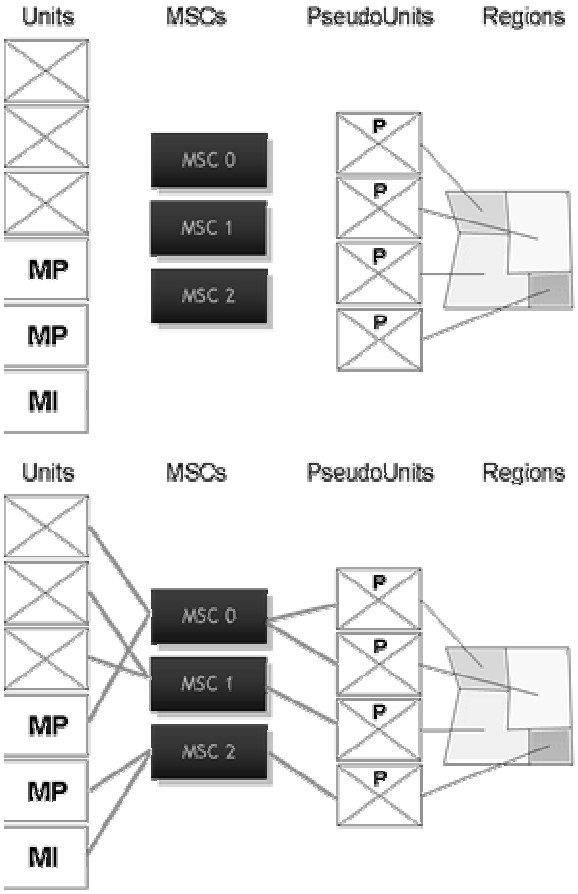

Figure 2. Initial conventional military units setup (top) and COA assignments (bottom)

clockticks in which all units have a chance to move, attack, incubate or entrench themselves. Therefore, the COA for media units is a list of regions to visit and the clocktick when each movement should take place. For units that are able to attack other units, the list of movements and times also includes a list of target factions. Each time the unit moves, it receives a new target faction. At the next opportunity, the unit searches for a target unit and attacks, causing an incident. However, certain factors can influence the success of an attack, such as the current strength or incubation status of the unit. Furthermore, unplanned attacks can happen when attitudes and animosities are high.

The conventional military units have a very different COA. These units, by default, belong to the friendly, or US, side and their COA consists of a force distribution among the regions. At initialization, the military expert defining the scenario has defined the regions and also the

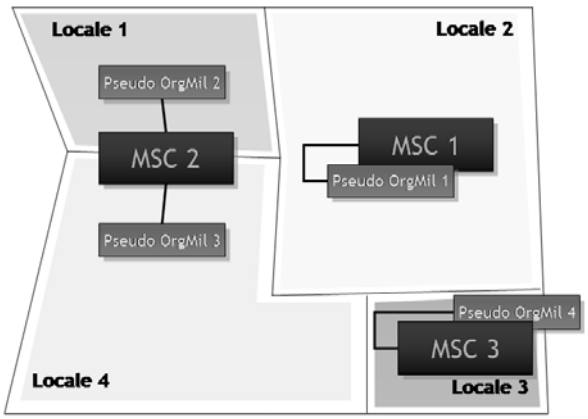

Figure 3. Pseudo unit military setup

number of major subordinate commands, or MSCs, as shown in the top of Figure 2. Each MSC is in charge of one or more regions. The COA determines which regions belong to which MSC and which conventional warfare units belong to which MSCs. The powers of the units are combined for an MSC and then distributed to the regions (via Pseudo Units which are placed in each region), according to terrain difficulty and size. An example COA appears in the bottom of Figure 2. Another example of MSC assignment to locales and distribution over Pseudo Units can be seen symbolically in Figure 3.

The next section discusses the Sheherazade simulation in detail. Again, the simulation runs once the COA has been generated in the coevolution algorithm. The simulation executes the COA and results in scores that are passed back to the coevolution. Therefore, the next section assumes that the COA has been passed to Sheherazade and the algorithm can begin its simulation.

4. Simulation algorithm

The Sheherazade simulation begins a scenario by initializing or calculating the initial parameters for all units (MSCs, militia, information operators, apolitical non-combatants and terrorists) and moving them to the starting regions as specified by the COAs. After the units have been allocated, the algorithm is ready to begin playing the game for the number of cycles (clockticks) specified by the user during game setup.

At each clocktick, all of the units' powers are calculated based on the characteristics of the new region if they have moved. Regions are then sequentially processed to update their attitudes. Next each region is checked for planned and spontaneous incidents. Finally, the units are checked to see if they need to relocate before the next clock tick and if so, they update their location parameters before the start of the next clock tick. They will then update their effective powers and footprints again based on the new locale's parameter values. The algorithm follows these basic steps:

```
Setup/initialize units
For each clocktick
    Calculate distributed parameters for units
    Check for incidents
        Terrorist hunt.
        Terrorist incidents
        Militia rules of engagement violations
        Demographic incidents
        Militia attacks
    Update unit locations
Report final scores
```

The next sections describe each step in detail.

4.1. Setup/initialize units

MSC units are assumed to have already been assigned to regions according to values in their COA as selected by the coevolution algorithm. This COA also decides the assignment of conventional military units between the MSCs. Initializing the MSC units involves accumulating the footprint, strength and powers (combat, IO and intel) of all of the conventional military units assigned to that MSC and factoring them by the MSC's support priority, number of MSC's, difficulty of the MSC and the number of regions the MSC covers. (The support priority for MSCs and the number of regions an MSC is assigned to cover are variables under the control of the MSC COA.) An MSCs initial strength is calculated as the average of the strengths of its conventional military units while its difficulty is the sum of the difficulties of each locale for which it is responsible (where difficulty is a factor of the regions area and terrain difficulty, specified by the game designer).

To simplify the computation of incidents which are processed region by region, MSC units are represented in the game by virtual or pseudo conventional military units. A pseudo unit basically represents the power and presence of the MSC in each of the regions the MSC covers, as shown in Figure 3. Any incident involving conventional military units is calculated within the simulation using these Pseudo conventional military units.

Setup for the militia and terrorist units initializes their current incubation times to zero, and for a militia sets the target faction of its first attack based on the militia's COA values. The effective combat power of a militia, which influences the damages assigned to the two parties involved in an attack incident, is also calculated. For the terrorist units, the current recovery time is initialized to

zero and its location is updated based on the first region specified in its hit list, which is decided by the terrorist's COA. The remaining units, information operators and apolitical non-combatants move to their starting regions based on their respective COAs.

4.2. Calculation of distributed parameters for units

Units in Sheherazade have two sets of values: actual parameters that are defined at setup by the user and effective parameters that are used by Sheherazade in the calculation of damages, effects on region attitude, faction animosity, etc. After the initialization of the unit values that are not region dependent, the sequence of game cycles begins by calculating the effective values for all the units and regions.

For a militia, its actual footprint, scaled by its current strength and the difficulty of the region in which it is located, determines the effective footprint. The effective IO power is a factor of the actual IO power, effective footprint, current strength and the population in the region that has the same alliance as the militia unit. It can be noted that while the actual footprint or IO power of a unit never changes, its effective parameters are directly influenced at every game cycle by its current strength and the characteristics of the region in which the unit is currently located.

The parameters calculated earlier for pseudo units that depend on variables that are liable to change over game cycles are recalculated. These include combat power, intel power, police power and effective IO power. Once again it should be noted that since pseudo units are defined and used as an abstraction within Sheherazade, the actual parameters of a pseudo unit represent the effective parameters (those that change over the course of a simulation) of other user-defined unit types. The IO power of a pseudo unit is simply the effective IO power of its MSC. Therefore the pseudo unit uses only one effective value, where the effective IO power is calculated as the product of its IO power and current strength.

Information operators and apolitical non-combatants only contribute to IO influence in the calculation of region attitudes (which influences a host of other factors) and are currently processed identically. The effective IO power is calculated as their IO power scaled by the population in the current region that has the same alliance as the unit, and the difficulty of the region.

After all the effective values for all IO units (pseudo, militia, information operators and apolitical non-combatants) have been calculated, the effective IO powers of the units in each region are added together to determine the IO power of the region. Each region's IO power then divides the effective IO power of the IO units to compute their weighted IO power. The weighted IO power of each unit is therefore a combination of the effective IO power of the unit in relation to the other IO units that contribute to the total IO influence in the region. This weighted factor is used in the calculation of region attitudes as described next.

4.3. Check for incidents

Once all of the units have been assigned values according to their current strengths and the region they are in, the SASO wargamer checks region by region for incidents. Incidents are checked in the following sequence: terrorist discovery incident, terrorist attack, militia ROE violation, demographic attack, militia attacks.

Since the attitude levels in the region directly influence incidents such as demographic attacks, region attitudes are updated before checking for incidents. Factors that decrease the attitude in a region include the police power of the region's pseudo unit (representing the effect of fair policing), and the weighted IO powers of the pseudo unit, each militia, information operator and apolitical non-combatant, and the police power of each militia in the region, if all of these units are of IO type calming. If the units are of IO type agitating, then their goal is to raise the attitudes in the regions, and their weighted IO powers contribute to the increase in the region's attitude. The accumulation of the above factors represents the pressure to change the attitude in a region. The pressure is filtered through a squashing function that basically increases the attitude quickly when it is low and slowly when attitude is already high and conversely, decreases the attitude quickly when it is high and slowly when it is low.

4.3.1. Terrorist hunt. Many factors contribute to the capability of the pseudo units' finding a terrorist unit in a region. The effective footprints of the region's pseudo unit and militias of IO type calming increase the capability while the region's attitude decreases from it. Moreover, the intel power of the pseudo unit increases the capability. After accumulating the factors, the calculated value for capability is categorized into weak, medium and strong probabilities for discovering a terrorist, corresponding to a 14%, 25%, and 40% chance of terrorist discovery respectively. If a terrorist is found based on this probability, its current incubation and recovery times are reset to zero and it is assigned a random attrition less than its normal recovery time. A discovered terrorist unit must wait until it recuperates from its attrition, before it can begin incubating again, as opposed to waiting only for the incubation time before launching its next attack.

4.3.2. Terrorist incidents. For each fully incubated terrorist operations unit in a region, the algorithm checks to see if the unit will cause an incident in the current cycle. A small percentage of the time, a ready-to-attack terrorist unit will simply find its plans foiled and its current recovery and incubation times will be reset to zero. Otherwise, the potential severity of the attack, calculated as a random percentage of the terrorist unit's combat power, is used to check if an incident is possible in this region. A possible incident requires the presence of a pseudo unit whose faction represents the terrorist unit's current target faction, or, if not found, a randomly selected militia unit of the target faction, or, if even a militia is not found, then a population in the current region of the target faction. If none of the criteria are met, the terrorist unit will have failed to find a target and its current incubation and recovery times are again reset to zero in preparation for its next mission. If either a matching pseudo unit or a militia was found, the unit's current strength is decreased by a factor of the calculated incident severity. Regardless of the type of the victim, the attitudes in the region are updated based on the incident severity and damages are added to the target faction. Finally, assuming a target was found among the pseudo, militias and region population, the effects of the incident on animosities is calculated, resulting in an increase in animosity of the victim's faction towards the attacking terrorist's faction.

4.3.3. Militia rules of engagement violations. A check for militia ROE violations proceeds in the same manner as a terrorist attack. For each militia unit in the current region, the SASO wargamer checks for the presence of a faction in the region that is of the same faction as the first militia's intended target. The wargamer uses the animosity matrix to verify that the militia's faction currently dislikes the target faction as the animosity could have changed over the course of the game. If animosity exists, a random ROE violation probability, based on the militia's ROE discipline and the animosity towards the target faction is calculated. The severity of the incident is calculated as a function of the animosity value. Next, as in the case of terrorist incidents, the wargamer checks whether an incident is possible in the current region (i.e. it searches for pseudo units, then militias, then a region population) and if a target is found, updates the target faction damages and strengths based on the value of the incident severity. Finally, the effect of the incident on animosities is computed.

4.3.4. Demographic incidents. A demographic incident occurs if any of the faction populations in the current region decides to attack a unit or local population belonging to another faction. The severity of a demographic incident is a randomly-generated severity value multiplied by the region's attitude. Depending on the degree of animosity that the attacking faction feels towards the victim faction, the region's attitude, and an imposed success rate of 10 percent, the wargamer proceeds to check for the possibility of an incident (i.e., it looks for pseudo conventional military units, militias, and region populations of the given enemy faction alliance, in sequence). If a target unit is found, its damages and strength are updated and the animosity effects are computed.

4.3.5. Militia attacks. A militia unit attacks if it has incubated for a period of time equal to the entrenchment time, which is a game constant. The algorithm first looks for a pseudo unit for the militia to attack. If the pseudo unit belongs to same faction as the militia's target, there will be an engagement. Otherwise, the algorithm computes the average of the militia's and pseudo unit's effective footprints, and combines it with the militia's ROE discipline and its animosity towards the pseudo unit's faction to determine an ROE rating which ultimately determines the probability of combat (Of course, if the factions are neutral or friendly, there will be no engagement.). If either of these two criteria for engagement is met, a combat incident is generated. The severity of the incident is calculated based on the average footprint, and it is multiplied by a normalizing factor based on the strengths of the militia and pseudo unit to determine damages to the two units. The strengths of the units are updated based on the damages, and the attitudes in the region are updated based on the severity.

If the militia unit does not attack the pseudo unit in a particular cycle, the algorithm searches for another target from among the other militia units in the locale. As with the pseudo unit, the alliance of the target militia unit is checked, and if different from the intended target faction of the attacking militia, the animosity of the attacking militia's faction towards the target faction is combined with the footprint overlap and the two militia units' ROE disciplines to determine the probability of an incident. The algorithm subtracts from the accumulated incubation time and applies an unprepared penalty to the calculated damages and strength of the targeted militia in the case where the militia was attacked while it was not yet fully entrenched.

4.4. Update unit locations

Based on the COAs received from the coevolutionary algorithm, all units are placed into the new regions according to their plans. Militia units recalculate their effective combat power based on the current strength and combat power which may have changed as a result of game incidents, and increment their incubation times. If

they need to move to a new locale, the incubation time is reset to zero. All terrorist units update their target information and move to the next locale if a new hit is specified. Otherwise, terrorist operations units that have fully recovered from a discovery and have the support of a terrorist operations unit in the same locale that supports

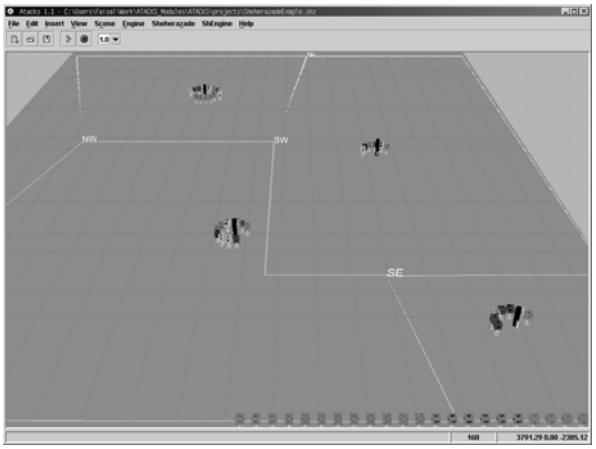

Figure 4. ATACKS sample display

its faction and is also not recovering, will increment their incubation times. Terrorist operations units that do not have the proper support may or may not increment their incubation time in any given cycle. Finally, if any terrorist unit has non-zero attrition, meaning it was recently discovered and is recovering, its attrition is decremented (and must reach zero before it can begin incubating again).

5. Sample game run

This section gives a brief demonstration of the Sheherazade wargaming engine by tracing through some of the algorithm steps. Figure 4 shows how a scenario with four locales is displayed in ATACKS. The clusters of unit objects represent the initial placement of units in each of the four locales based on their respective COAs. As each cycle is processed in ATACKS, units that update their locations based on their COAs are shown moving across the map.

Figure 5 shows two graphs of the attitudes for the four regions (northwest, northeast, southeast and southwest) in the scenario over a game of 80 cycles. These two graphs illustrate two different sets of COAs. The attitude graph on top represents a faction COA that tries to increase (agitate) region attitudes. The lower attitude graph represents a US COA that counters the COA generated for the top graph. In this case, the simulation for the top graph resulted in a very agitated NW region. The lower graph shows all regions have calmed by the end of the run. In addition to graphing the attitude levels, the attitude graph textually lists all incidents occurring in a region at each clocktick. ATACKS provides several more line graphs depicting damages to factions, animosities, unit strengths, and any other unit values that the user chooses to graph. Examples and explanations of these graphs can be found in [3].

Another type of display contains colored stripes for the locales and icons for the units, graphed over time. For example, the display in Figure 6, graphs all incidents that occur at each region for each clock cycle. Like the

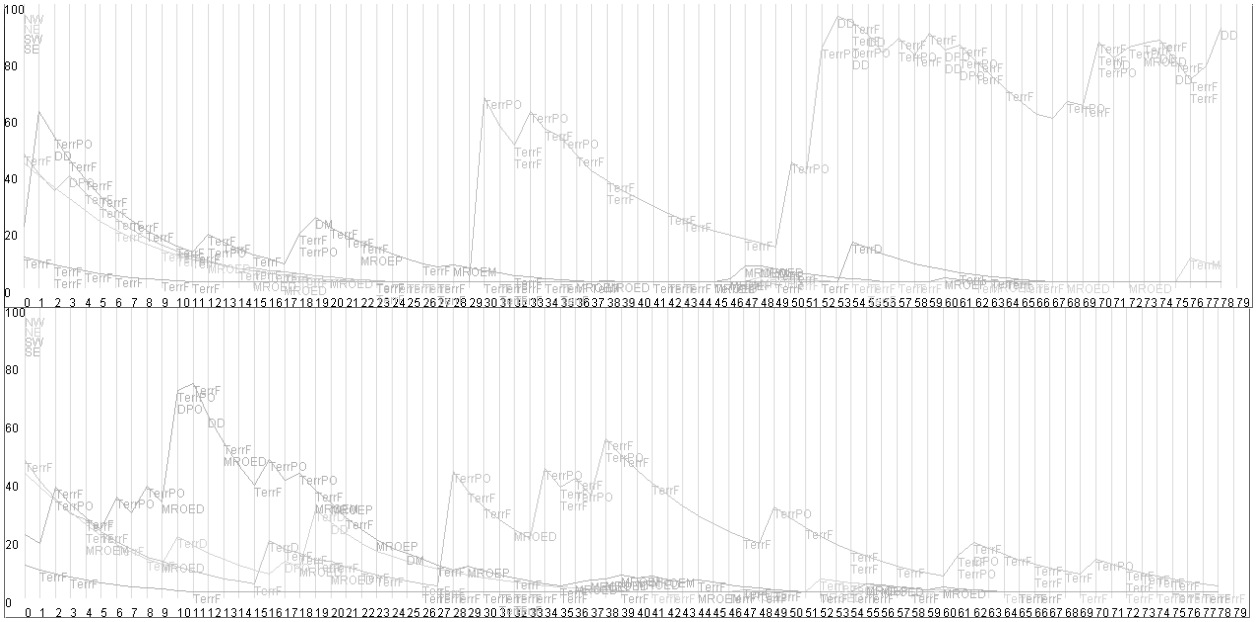

Figure 5. Locale attitude graphs for an enemy faction COA (top) and a US faction COA (bottom)

attitudes display, each region in the incidents display is represented using a different color so that the incidents taking place in each region are readily distinguishable. In the display, a number of terrorist discovery incidents (labeled TerrF in Figure 6) can be observed in the northwest (top) region between clock cycle 23 and 27. The units involved in the incidents bear the standard military symbols for unit types and are also color coded to represent the faction they belong to. Hence, it can be further observed that two terrorist operations units belonging to the Eastern Alliance faction were discovered in the northwest region at game cycle 23, whereas one terrorist support unit of each of the factions Eastern and Northern Alliance were discovered in the southeast region at game cycle 27. The unit icons also have a small bar indicator to the right to convey the severity of the incident.

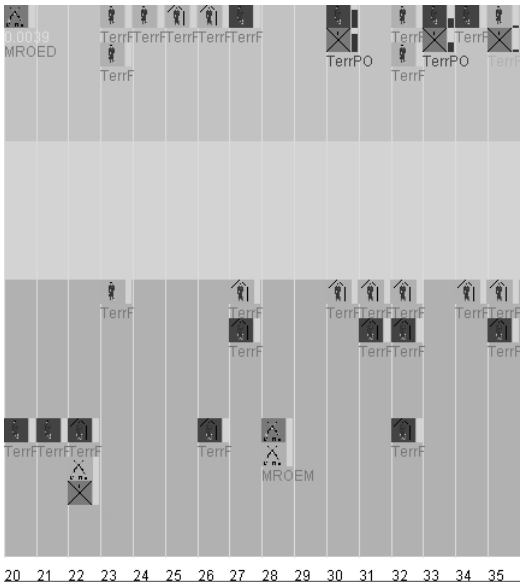

Figure 6. Incidents display (from top: northwest, northeast, southeast and southwest locales)

Coming back to the spikes in the attitude graph, it can be seen that a terrorist attack with fairly high severity was carried out against the pseudo unit (the icon for the victim of the attack is drawn below the perpetrator's icon) in the northeast region at time 30, causing the attitude spike. Furthermore, based on the color of the attacking terrorist unit, the allegiance of the attacking terrorist is seen to be the Northern Alliance faction.

6. Conclusion and future work

This paper presented a comprehensive description of the Sheherazade SASO simulation model. A terrorist attack incident was traced with the help of displays generated by the ATACKS visualization platform to correlate SASO incidents to the effects on the soft factors such as attitudes in regions and faction animosities.

This system is unique in its attempts to incorporate concepts from conventional warfare with SASO type units and qualitative effects such as attitudes and animosities. As a first attempt to model this complex and varied environment, the Sheherazade simulation has produced interesting behaviors that reflect the richness of the environment.

Currently, the SASO simulation engine is undergoing model validation sessions with military experts. These sessions should decrease discrepancies between the simulation outcomes of battles and what is expected by the experts. They should also be a good indicator of how closely the system matches military intuition. Due to the probabilistic nature of certain events in the Sheherazade model, and the many interrelationships between the simulation's variables, it is not always easy to conclude quickly which particular events are responsible for a certain result. Introspection tools that help keep track of the deeper cause and effect relations would be a valuable future addition to the suite of visualization and analysis tools provided by ATACKS.

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