A Comparative Study of Simulation Software for Modeling Stability Operations

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ABSTRACT: *There are several software tools available for modeling combat and social phenomena. With more emphasis being shifted to the study of Irregular Warfare from Traditional Warfare it is important to evaluate current combat models to see if they can effectively model the complex situations that are faced by today's war fighters. This study evaluates three simulation software products: Map Aware Non-uniform Automata (MANA), Pythagoras, and NetLogo. An attempt to model a civil violence scenario and a segregation scenario is made using each software model. Then each system is evaluated for ease of use and functionality for modeling stability operations.*

1. Introduction

Recent military operations in Iraq and Afghanistan have shown that the old methods of fighting wars are no longer appropriate for every combat situation. Major challenges such as counterinsurgency operations and nation building require a new way to look at modern warfare and a new set of models and simulations to help the military leadership understand the nature of the battle space and make sound decisions and to help train soldiers who will be out in the field and have to react to situations not found in regular combat.

According to Department of Defense (DoD) Instruction 3000.05 issued in 2009, it is DoD policy that "stability operations are a core U.S. military mission that the Department of Defense shall be prepared to conduct with proficiency equivalent to combat operations." (2) There are several simulation tools available to help the military prepare for and conduct stability operations such as the Peace Support Operations Model (PSOM) and the Human Cultural Social Behavior Model (HSCBM). The goal of this study is to evaluate if other tools can be effectively used to model cultural behaviors the military may encounter in the field today. Three simulations have been chosen for comparison in this study: Map Aware Non-uniform Automata (MANA), Pythagoras, and NetLogo.

1.1 Problem Statement and Relevance to Stability Operations

With the recent shift in focus of U.S. military operations from traditional combat to security, stability, transition and reconstruction (SSTR) operations it is important to evaluate the ability of our modeling and simulation tools to meet the needs of the military. It is time consuming and expensive to develop simulation tools from scratch, therefore it is necessary to attempt to leverage existing models to meet the demands of a changing battle space.

This study will evaluate MANA, Pythagoras, and NetLogo, three existing software models, for their ability to model concepts related to stability operations. A segregation scenario and a civil violence scenario will be simulated using each of the three models and their strengths and weaknesses will be explored.

1.2 Referent and Conceptual Model

NetLogo has an extensive library of models available for use including several relating to social science theory. Two particular models were chosen for this study based on their potential relevance to SSTR operations.

Segregation Scenario

The first model is a segregation model which is based on studies of artificial societies conducted by Thomas C. Schelling in the late 1970's (Rauch). In this model there are two types of agents randomly placed on a grid. Each agent is programmed with a desire to have a certain percentage of its neighbors be of the same type as itself. If the number of neighbors of the same type is below this threshold then the agents will move around in the grid until they are "satisfied" with their neighbors.

Schelling discovered some interesting phenomena when running this model under various settings. It seemed that even with the smallest desire to be near neighbors of the same type, clusters of similar agents would be formed. Situations similar to this may occur in foreign campaigns where there are different ethnic groups or warring factions living in close proximity to each other. The ability to model the segregation scenario with a certain simulations tool could provide an indication of its usefulness in stability operations.

Civil Violence Scenario

The second model is a civil violence model designed by Joshua M. Epstein, a social scientist and computer modeling expert at the Brookings Institute. This model attempts to simulate the dynamics of a central authority trying to suppress a decentralized rebellion (Epstein, 7243).

This model has two basic types of agents, police and locals. The locals will tend to "rebel" based on their perceived hardship level and the legitimacy of the government. If the locals rebel they may be arrested by the police and will have to serve a jail sentence of random length up to some limit. As the locals rebel or go to jail they will change colors so visual patterns can be studied as the model is run.

The civil violence model is more complex than the segregation model due to the different states the agents can be in and the various parameters that can be adjusted. While more complex, the civil violence model is more applicable to situations the U.S. military could see in future combat operations, so it is valuable to use this model for this study.

1.3 Model Selection

This study evaluates three models for their ability to simulate and analyze situations that may be found in SSTR operations. The three models chosen were Map Aware Non-uniform Automata (MANA), Pythagoras, and NetLogo. The three models were chosen due to their similarities as agent-based models which can model Complex Adaptive Systems and explore group phenomena and their ease of installation on a personal computer.

1.3.1 Map Aware Non-uniform Automata (MANA)

MANA is an agent-based distillation model developed by the Operations Analysis group at the Defence Technology Agency (DTA) in New Zealand. It was designed as a variant of Cellular Automata Models for modeling Complex Adaptive Systems (CAS) for combat situations (McIntosh, iii). The features of MANA make it particularly useful for modeling and analyzing the effects of situational awareness, command and control, and enhanced sensors.

MANA has been used in several military and academic environments with some uses specific to SSTR Operations. Some uses include modeling civil violence management, investigating warfare as a complex adaptive system, modeling of maritime surveillance and coastal patrols and a range of studies carried out at the bi-annual Project Albert meetings. It has also been used for several Master's theses at the Naval Postgraduate School (NPS) in Monterey, CA.

1.3.2 Pythagoras

Pythagoras is also an agent-based distillation model developed by Northrop Grumman to support Project Albert, a U.S. Marine Corps sponsored international initiative focusing on human factors in military combat and noncombat situations (Bitinas, 45). Pythagoras uses "fuzzy logic" to allow for more uncertainty in the actions of agents in a given scenario. For example, instead of giving a firing range threshold of exactly 50 meters the user can assign a range of 45 – 55 meters as the threshold and the simulation will randomly pick a value in that range. Pythagoras introduces unique capabilities such as soft decision rules, sidedness, behavior change triggers, and nonlethal weapons.

There is a long list of military applications of Pythagoras. Some that could be used in a stability operations context include: peacekeeping at night in an urban environment, conceptual models of human factors in terrorist situations, less than lethal technology for urban combat, and competition between multiple factions when securing targets of interest.

1.3.3 NetLogo

NetLogo is an Interactive Display Environment (IDE) for creating programs to simulate natural and social phenomena. It was authored by Uri Wilensky and has been further developed at the Northwestern University Center for Connected Learning. NetLogo is adept at modeling complex systems that develop over time and has a large library of example programs that could be easily adapted for military uses.

Dr. Stephen Hall, a research professor at the Modeling and Virtual Environment Simulation (MOVES) Institute at NPS has used NetLogo extensively for several military applications. Some examples of his work include: coast guard deterrence, distributed sensor tracking and location, collaborative high-energy laser (HEL) weapon engagement, and adaptive organization exploration. Although these examples may not have obvious applications to stability operations, NetLogo has potential value for evaluating scenarios in the field of irregular warfare.

3. Scenario Creation with Each Modeling Software

3.1 Segregation Scenario

As discussed previously, both scenarios were already created in the NetLogo models library. The attempt was then made to create similar phenomena using both MANA and Pythagoras.

3.1.1 NetLogo Segregation

The NetLogo version of the segregation model is described as follows:

> "This project models the behavior of two types of turtles in a mythical pond. The red turtles and green turtles get along with one another. But each turtle wants to make sure that it lives near some of "its own." That is, each red turtle wants to live near at least some red turtles, and each green turtle wants to live near at least some green turtles. The simulation shows how these individual preferences ripple through the pond, leading to large-scale patterns" (Wilensky).

The initial setup of the model randomly places 2000 red and green "turtles" in a grid and assigns a parameter of Percent-similar-wanted of 30%. When the model is run the turtles will move around until they satisfied with the percentage of similar neighbors. Below is a screen shot of the model after it has been run until steady state is reached under the initial conditions discussed above.

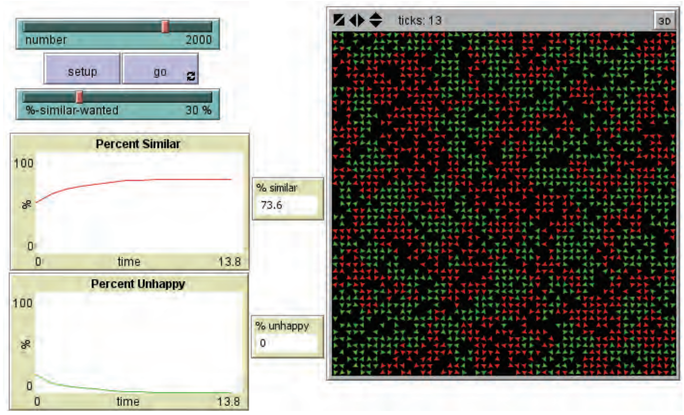

Figure 1 – NetLogo Segregation (30% Similar)

One feature of NetLogo is the ability to embed charts in the IDE to show the changes in desired parameters as the model is run. Sliders can also be added to adjust parameters, which in this case is the number of turtles and %-similar-wanted. If the %-similar wanted is adjusted to a higher value, such as 70%, the pond will develop a more stark division of red and green turtles as would be expected.

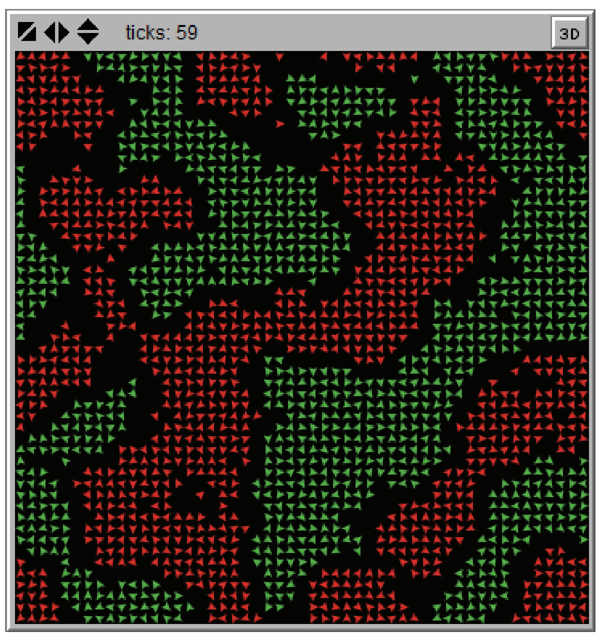

Figure 2 – NetLogo Segregation (70% Similar)

Another valuable feature of NetLogo is that you can change the values of parameters while the simulation is running and get instant feedback, either visually or via the graphs, of how the change affects the model.

3.1.2 MANA Segregation

The next step was to try to recreate similar behaviors to those seen in the NetLogo segregation scenario using MANA. The setup of this scenario was fairly straightforward. There are two squads of agents, red and blue, with their weapons disabled, placed randomly in a 100 by 100 grid area. The agents on either side were then assigned a tendency level to be attracted to agents of their own kind and a slight tendency to stay away from dissimilar agents. The initial layout of the agents is shown below in Figure 3.

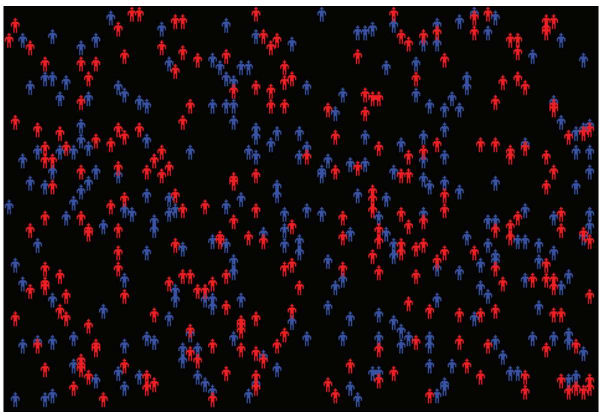

Figure 3 – MANA Segregation Pre-run

When the scenario was run the red and blue entities tended to form tight clusters of similar agents similar to the NetLogo example. The behavior is not exactly the same as in NetLogo because the agents are simply drawn to their kind vice having a certain threshold of similar neighboring agents. Even if there was a very low setting of attraction between similar agents, the clusters still formed, it just took longer. An example of the steady state condition is shown below in Figure 4.

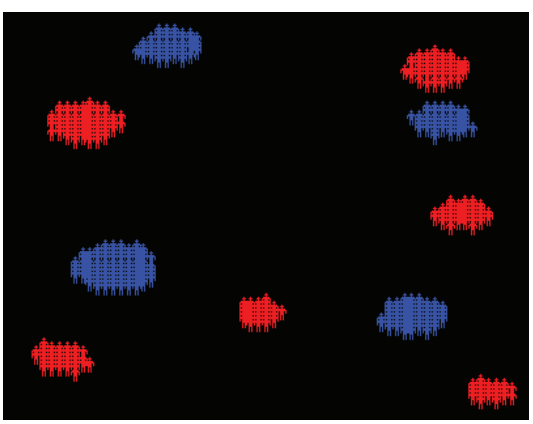

Figure 4 – MANA Segregation Post-run

3.1.3 Pythagoras Segregation

The scenario setup in Pythagoras was similar to that of MANA. There were blue and red agents randomly assigned in a 100 by 100 grid with no weapons. They were then given movement desire levels based on friendly and enemy units nearby. In Pythagoras a movement desire probability can be assigned as well as a distance threshold. To get a similar phenomenon in MANA, the sensor range would have to be adjusted to affect the distance of attraction or repulsion. Before and after screenshots of the Pythagoras segregation model are shown in Figures 5 and 6 below.

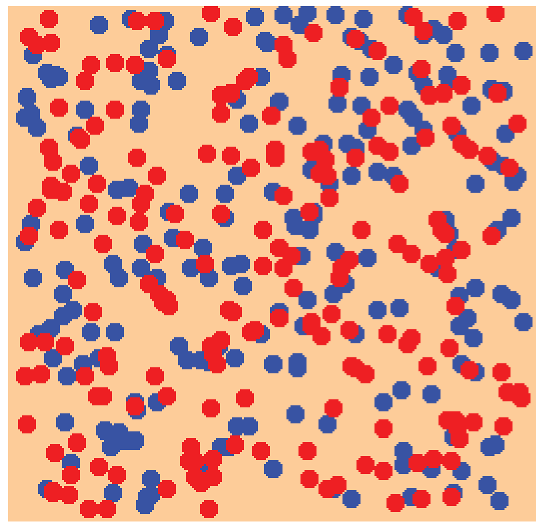

Figure 5 – Pythagoras Segregation Pre-run

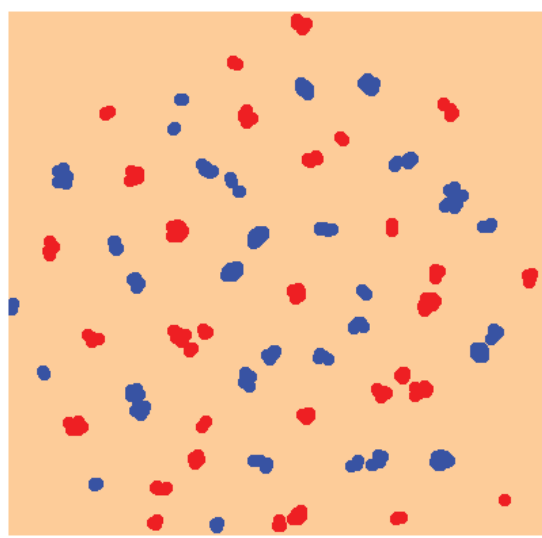

Figure 6 – Pythagoras Segregation Post-run

The clustering behavior in the Pythagoras scenario is similar to the MANA scenario except the clusters tend to be of fewer agents. The reason for this behavior is that the setting of attraction is to move to closest neighbor, therefore if two similar agents are together they will be content and no longer move towards other friends. An alternate method would be to trigger a behavior change when there are too few friends in the vicinity. This method is slightly more complex but was not attempted as part of this study.

3.2 Civil Violence Scenario

Once again the baseline scenario for this study was taken from the NetLogo models library and is entitled "Rebellion." This scenario is significantly more complex, but somewhat similar behaviors were created using MANA and Pythagoras.

3.2.1 NetLogo Civil Violence

The NetLogo civil violence model closely follows the model created by Joshua M. Epstein. The two types of agents are locals, represented by green circles, and police, which are blue triangles. The agents can move about randomly in the grid. The locals have a variable grievance level, which is based on a combination of their perceived hardship and the government legitimacy. The shade of green of the locals will change with their grievance level. An initial setup of the NetLogo scenario is shown below in Figure 7.

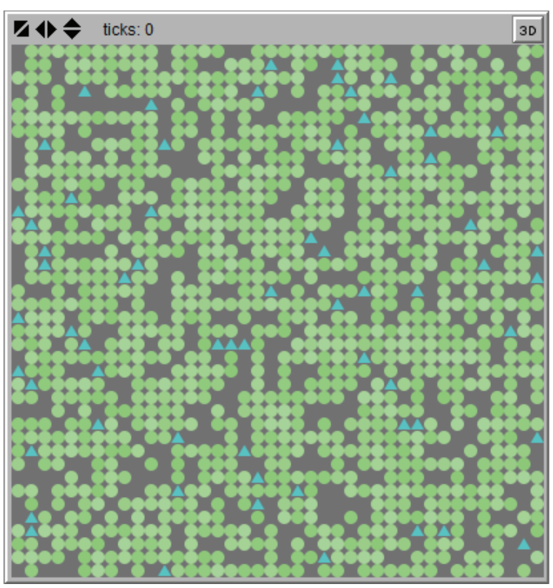

Figure 7 – NetLogo Civil Violence Initial Setup

As the scenario runs the local agents may rebel based on their grievance level and a risk of being arrested, which is based on the number of police and rebelling agents in the vicinity. If an agent rebels it becomes a red circle. The police will arrest rebelling agents and they will serve a jail term up to the limit set by a slider. When an agent is in jail is will become a black circle.

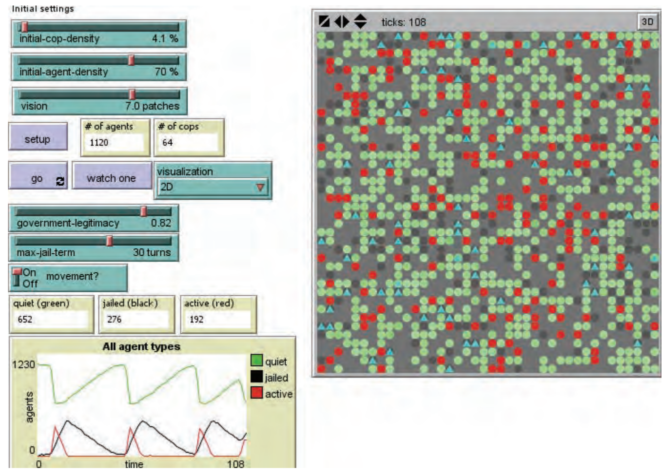

Figure 8 – NetLogo Civil Violence Running

Figure 8 above shows the scenario while it is running. There is a graph that shows the number of quiet, jailed, and active agents over time and sliders to control several variables in the model. One interesting feature of the NetLogo model is the "watch one" button. This allows the user to track an individual agent as it moves through the grid and see it state changes.

3.2.2 MANA Civil Violence

Some of the behaviors of the civil violence model were reproduced using MANA, but in some cases the underlying reasons for the behaviors were somewhat superficial. The initial setup, shown in Figure 9, has randomly placed blue agents (police) amongst a population of neutral yellow agents (locals).

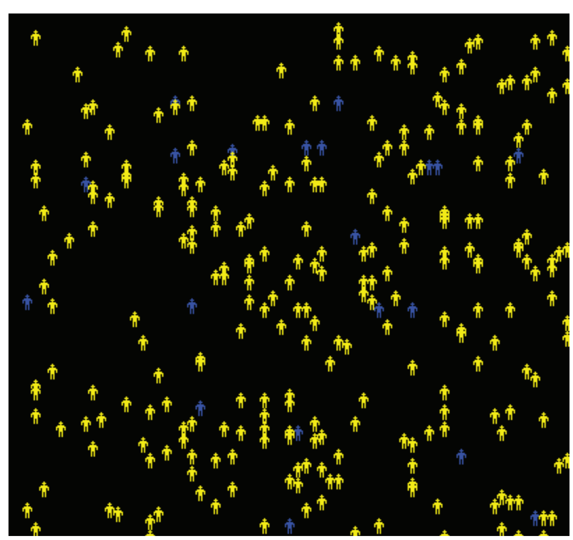

Figure 9 – MANA Civil Violence Initial Setup

The algorithm to make the locals rebel was only based on coming into contact with police agents, which is far less complex than in the NetLogo model. As the agents rebel they turn red and the police will then perceive the rebelling agents as enemies and will shoot at them. The police weapons are set to be non-lethal so it will not kill the rebels, but it will trigger a state change which represents an agent being in jail. When the agents are in jail their color will be magenta and their jail sentence will be a random time period up to a set limit as in the NetLogo model.

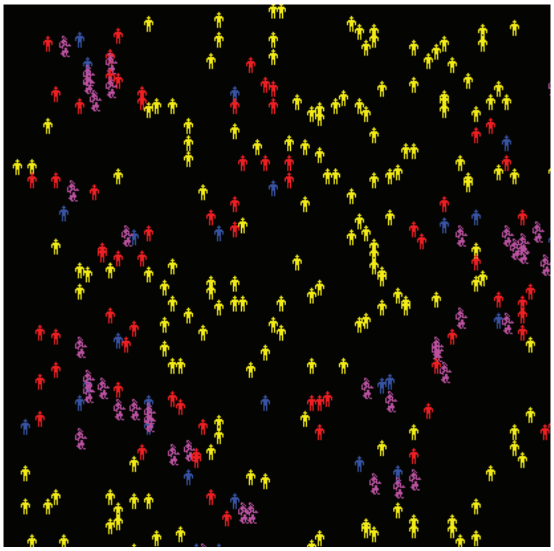

Figure 10 – MANA Civil Violence Running

Overall the MANA model behaves similar to the NetLogo model, but its greatest shortcoming is the limited ability to model the parameters that trigger the rebellion phase of the local agents.

3.2.3 Pythagoras Civil Violence

Pythagoras is more flexible than MANA in that the user can vary the sidedness of the agents. The agent can have a color level from 0 to 255 of red, green, or blue and the agents can be set to interact with each other as friends or enemies based on their color values. This characteristic was exploited when setting up the civil violence scenario in Pythagoras. The initial setup was similar to MANA with red agents being locals and blue agents as police. The locals were equipped with non-lethal weapons that could be used to persuade other agents to go active based on their color value. The police were also given a non-lethal “arrest” weapon which would target rebelling agents and change their state to simulate being in jail. Figure 11 shows an example of the initial setup of the civil violence model.

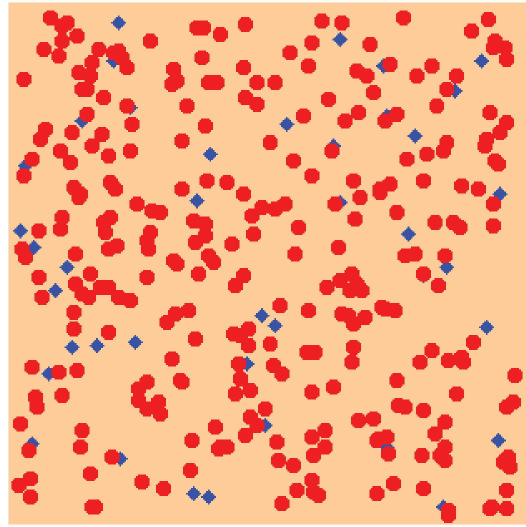

Figure 11 – Pythagoras Civil Violence Initial Setup

As the scenario runs the rebelling agents will turn green and when they are arrested they will turn purple and eventually return to red as shown in Figure 12. Overall, Pythagoras does a reasonable job at modeling the interactions of Epstein’s civil violence model.

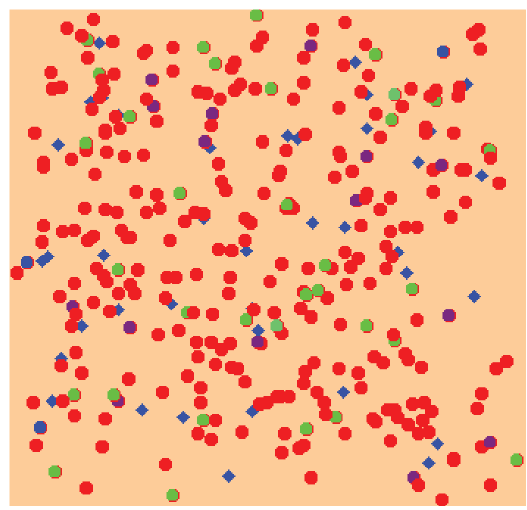

Figure 12 – Pythagoras Civil Violence Running

4. Comparison of Software Tools

4.1 Ease of Use

Both MANA and Pythagoras have their own Graphical User Interface (GUI) so they have convenient menus, pop-ups and buttons which make the system straightforward to use.

MANA was the easiest to learn from scratch and to have a simple, working scenario within minutes. There is a helpful tutorial in the MANA user guide that walks the user through the basic steps of creating a scenario and helps quickly build a good knowledge base.

Pythagoras also has a user guide with tutorials, but there are so many different tabs and inputs that could be manipulated that it can be overwhelming to someone who is not a system expert. According to the Pythagoras user guide, “The software should be able to be used by a Marine History-major with less than eight hours of training” (Northrop Grumman). Based on the complexity of this software tool this does not seem achievable.

NetLogo is basically an IDE and has its own programming language under the hood that a user would have to become familiar with before being able to make models. There is extensive documentation of the programming language and syntax similar to Javadocs that would aide a novice user. Also, the models library provides many example programs that also have good documentation, which could be tailored to meet the needs of a certain problem.

4.2 Functionality

MANA seems like it would be best suited for traditional combat operations where the agents had limited states they could be in. The interactions of agents are limited in MANA to a set list and cannot be tailored to every situation. Also, the system slows down significantly when too many agents are added. For example, in the segregation scenario the NetLogo model easily handled 2000 agents, but the MANA scenario was limited to 600 before the program virtually came to a halt.

Pythagoras has more flexibility imbedded in the software for modeling more complex interactions between agents. The ability to vary the sidedness of the agents is critical for studying the interactions of different ethnic, political, or religious groups in a wartime environment. Similar to MANA the system did bog down when too many agents were added to the scenario.

Since NetLogo has its own programming language the rules of the scenario can be specifically tailored by an adept user. NetLogo also has useful tools such as built-in graphs and sliders to change variables while the scenario is running that are not found in Pythagoras or MANA. Both MANA and Pythagoras have a data output feature, but the data then has to be plotted separately using a tool such as Excel. Also, the parameters of a scenario cannot be changed during a simulation run in MANA or Pythagoras.

5. Results and Conclusions

All three of the models analyzed in this study have potential uses in modeling SSTR Operations. MANA is better suited for combat modeling but could be used for irregular warfare operations in an urban environment, which is an element of SSTR Operations. Pythagoras is well suited for modeling stability operations and complex social interactions because of its soft decision rules and ability to model varying sidedness of agents, but requires more experience to master. NetLogo has the most potential for dynamically adjusting scenarios and studying the interactions of agents under varying situations, but is only as good as the programmer creating the models.

A study in 2005 was conducted by the Land Operations Division Systems Sciences Laboratory of the Australian Department of Defense to determine if NetLogo was suitable for modeling civil assistance and guerilla warfare. The study concluded that, “NetLogo is shown to be capable of modeling a subset of physical, social, and behavioral interactions in guerilla warfare and in that capacity is useful for developing conceptual models and providing insights into the nature of guerilla warfare in low-fidelity preliminary studies” (Wheeler).

6. Lessons Learned, Recommendations, and Future Work

This study showed several strengths and weaknesses of current simulation software tools for the modeling of SSTR operations. It has been demonstrated that there are several tools already available to the war fighter that can be leveraged for stability operations without the need to create an entirely new product. MANA, Pythagoras, and NetLogo are all examples of software that can be used to explore interactions that are important in today’s combat and support operations.

There is further research that could be conducted to advance this study. More models could be included in the study to see if there are other products available for modeling stability operations. Also, a study could be conducted of simulation tools for training various levels of soldiers and leaders in SSTR Operations. Another route would be to take the strengths of each software program and attempt to implement them in one of the existing models to get the best possible product for modeling stability operations.

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