An Agent-Based Serious Gaming Application Targeting the Training of Military Staffs in Urban Operations

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ABSTRACT

In this work we introduce an in-house developed agent-based serious gaming application targeting the training of military staffs, at the operational level of warfare, within the military operations in urban terrain domain. The application aims to stimulate the decision making process of military staffs during planning, execution and assessment of urban operations. In a typical game the military staff is initially presented with a mission order including mission objectives as well as a simulated perspective that visualizes the perceived state of the civilian population, friendly forces or known enemy threats. Using this information the trainees must continuously plan the activities and actions to be performed by friendly forces such as patrolling an area or setting up temporary checkpoints to gather information to ultimately improve situational awareness. The trainees must also monitor the execution of the planned activities to properly respond and re-plan whenever unexpected events such as plan deviations, crowd formations, enemy attacks occur within the game. Finally, the trainees must assess and report back its progress to the strategic leaders, which is typically played by the exercise leader in the game.

Our application simulates the tactical behaviors, actions and activities, of friendly forces as well as enemy threats represented by irregular forces or explosive devices. The main novelty of our work is the integration of an agent-based model representing the civilian population. The population model simulates everyday, routine behaviors, as well as the dynamics of opinions within the population with respect to for instance the regime or the presence of military forces within the city. Simulated opinions are used in the application to affect the decision making of the trainees but also to influence the behavior of civilians within the population. For instance, an individual in the simulated population that does not appreciate the presence of military forces will be less likely to share potentially valuable information with the military forces which in turn has a negative effect on the situational awareness of the trainees.

In addition to describing the details of the actual application, this paper also presents the conceptual design and implementation of a scenario where learning goals associated with cultural awareness and risk assessment are addressed.

1 INTRODUCTION

The training and preparation of military personnel for urban operations (UO) is a challenging task for any military school or organization. The training needs to consider not only the complexity of the urban terrain and enemy threats but also the civilian population including its culture, religion and opinions (e.g. their attitude towards the regime or the military forces).

UO training is typically performed using live exercises within real-world environments or, perhaps more often, in mock-up environments representing only a fraction of the real-world. Live exercises are ideal when training at the tactical level to, for instance, prepare military units or groups to move safely within the terrain, carry out patrolling operations, setting up checkpoints, as well as facing opponent forces in f re-f ghts. There are also numerous commercial simulation tools available today that can be used for UO training using virtual, high-quality, 3D environments. Live exercises and virtual simulators are, however, limited in the sense that they typically do not involve the larger civilian population, or green actor, which in many training scenarios is of utmost importance.

This work is an attempt to address this shortcoming. We have developed a serious gaming application targeting the training of military staffs where the civilian population is modeled and simulated in a virtual environment. The application aims to stimulate the decision making process of military staffs, at the battalion level, during planning, execution and assessment of UO. In a typical game the military staff is initially presented with a mission order including mission objectives as well as a simulated perspective that visualizes a map of the geographical area, the perceived state of the civilian population, friendly forces and known enemy threats. Using this information the trainees are assigned to:

- Identify a high-level strategy addressing the mission objectives.
- Convert the strategy to concrete plans consisting of activities and actions to be performed by the friendly forces (e.g. patrolling an area, setting up checkpoints).
- Monitor the execution of the planned activities to properly respond and re-plan when unexpected events such as plan deviations, crowd formations, enemy attacks occur.
- Assess and report back progress to the leader of the military staff (e.g. commanding off cer or strategic leader), which is typically played by the exercise leader in the game.

The serious gaming application we have developed can be used to implement a wide variety of training scenarios using different levels of complexity (i.e. time pressure, threat level, situational awareness uncertainty). In this paper we have designed and implemented a scenario where we focus on the trainee's ability to improve situational awareness while considering the risks of being attacked by enemy forces. Our scenario emphasizes the importance of winning the hearts and minds of the population by simulating the population's opinion with respect to its attitude towards the military staff and its military forces. In this scenario the opinion affects the behavior of the population such that individuals that like the military forces are more likely to share information such as whereabouts of threats, suspicious enemy activities and infrastructure failures. Similarly, individuals that dislike the military forces may begin to sympathize with the opposing forces and provide them with information such as checkpoint locations and patrol routes which makes it even harder for the military staff and its forces to safely operate within the city.

This document has been organized as follows. In Section 2, we introduce the POPSIM platform, which we have used and extended to implement our serious gaming application. In Section 3, we describe the conceptual design of the proposed scenario. Section 4 describes the implementation of the scenario using POPSIM as well as preliminary experimental results. Finally, conclusions and future works are presented in Section 5.

2 POPSIM: HUMAN POPULATION SIMULATION

POPSIM is an extensible platform consisting of several reusable components targeting the modeling and simulation of human populations in urban terrain [6]. POPSIM employs an Agent-Based Modeling (ABM) approach where each individual in the population is represented by an agent that governs its own knowledge-base and sense-reason-act cycle. The ABM approach was chosen, over equation based approaches, mainly because it is extensible, intuitive and relatively easy to communicate and explain to our end-users [2].

The POPSIM platform includes:

- A population synthesizer used to generate the initial state of the agents in the population. The synthesizer generates demographic properties (e.g. gender, age, occupation, health), geographical properties (e.g. home, work-place) and relationship properties (e.g. friends, family).
- A routine behavior model used to generate plans representing everyday activities such as working, sleeping and eating for each agent in the population.
- Infrastructure models providing basic services (e.g. water, electricity, cell-phone communication, roads) for the agents in the population.
- Terrain analysis and reasoning algorithms used by the agents to calculate line-of-sight (LoS), f eld-of-view (FoV) and paths or routes between two or more points within the terrain.
- Opinion dynamics models used to simulate opinions or attitudes within the population and how opinions may change when agents meet and communicate with each other one-on-one or in larger groups in the population.
- Real-time visualization using super-imposed geographical maps illustrating for instance spatial heat-maps of population density and opinions. The platform also provides line and bar plots to illustrate the dynamics of the population with respect to activities, health-state, opinion, etc.
- Registration functionality to facilitate off-line analysis using external tools.

An in-depth description of POPSIM including other examples of practical applications or case-studies where POPSIM has been used in the past can be found in [6].

2.1 Serious gaming using POPSIM

To implement our serious gaming application we extended the POPSIM platform. First, a planning tool was developed which allows the trainee to generate plans that can be fed into and executed by the POPSIM simulator. A plan consists of one or more orders that, similarly to the Coalition Battle Management Language (C-BML) [1], consists of one or more tasks where each task details the *what*, *when*, *where*, *who* and *why* elements of an operation. Next, a set of analysis functions was developed with the purpose of generating quantitative metrics that can be used to measure and compare trainee performance. Our analysis functions are specif cally developed to quantify the trainee's estimated perception, or situational awareness, of the environment vs. the simulated truth. Finally, we have extended POPSIM to allow multiple clients to connect and interact with POPSIM in a networking, or multiple-player, environment. Besides allowing multiple players to interact with the application we use networking to distribute the trainee's perspective, or collection of views, to multiple screens. Figure 1 illustrates the client application which includes: a simulated time view; a command and control view; a time-line view capable of visualizing planned activities; a report view used to list incoming reports originating from own forces, civilians, or other agents; a map view used to visualize the locations of military forces and threats as well as buildings, roads, etc.; a mission order view describing scenario background and mission objectives; line- and bar-plots to monitor properties such as the health-state of the military forces and the population's attitude or opinion.

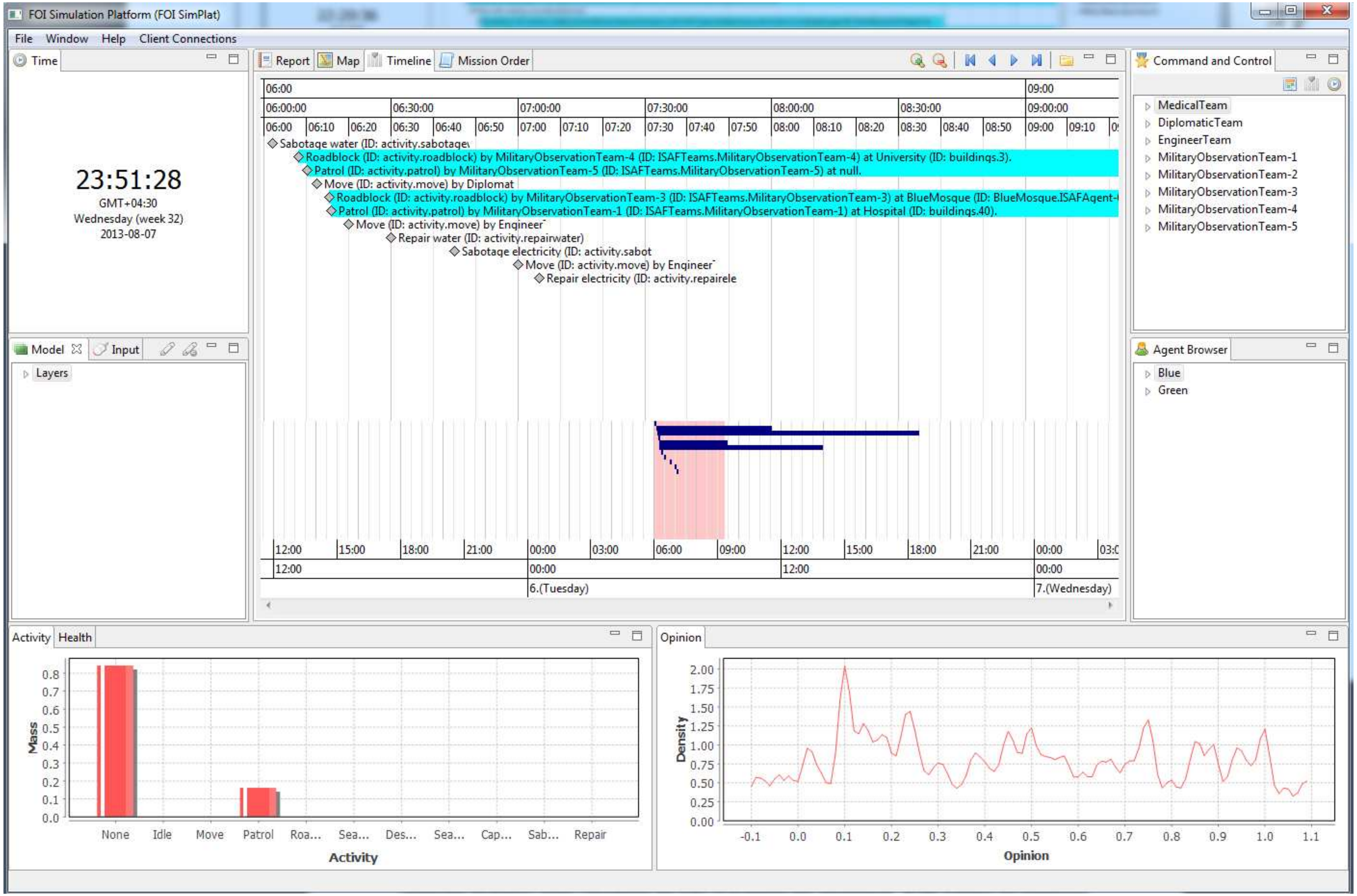


Figure 1: A screen-shot illustrating the client application used by the trainee to plan, execute and monitor missions. The main views of the client are: a simulated time view; a command and control view; a time-line view capable of visualizing planned activities; a report view used to list incoming reports originating from own forces, civilians, or other agents in the simulation; a map view used to visualize the location of military forces, threats, etc.; a mission order view describing scenario background and mission objectives; line- and bar-plots to monitor properties such as the health-state of the military forces and the population's attitude or opinion.

3 SCENARIO

The general learning goal of the scenario is to enhance the trainee's ability to acquire information to improve situational awareness while considering the risks of acquiring this information. In the scenario we emphasize the importance of winning the population's hearts and minds with respect to its attitude or opinion towards the military staff and its military forces. The abovementioned general learning goal can be split into the following, more concrete, sub-goals that strives to enhance the trainee's ability to:

- Consider and assess information (i.e. mission order, mission objectives, background information, intelligence, etc.) and using this information to develop eff cient plans to improve the military staff's situational awareness.
- Consider and assess the risks involved with urban operations with respect to:
  - Known and unknown threats (e.g. IEDs, irregulars) in the geographical area.
  - State of the population (e.g. against, neutral or supportive with respect to the military forces).
- Consider and analyze the urban terrain and infrastructure (i.e. buildings, roads, power grids, water/sewage systems, etc.).
- Consider and deal with cultural events and celebrations.

Given the learning goals we have created a conceptual design of the scenario considering input and feedback from domain experts in the urban warfare domain as well as technical experts (e.g. programmers, simulator experts) capable of eliminating design aspects that cannot be implemented due to technical limitations of the simulation software. The conceptual design represents a shared view, or common understanding, of the scenario and it is used as input not only during the scenario implementation phase but also when introducing and explaining the scenario to exercise leaders.

To design our scenario we f rst developed a causal diagram, see Figure 2, that visualizes the relationships between the main actors, their activities and main variables. The scenario includes three main actors: the blue actor represents the military staff and its military forces; the red actor represents opposing forces, irregulars and threats; and f nally, the green actor represents the civilian population. In the scenario the trainee manually controls the activities of the blue actor whereas the activities of the red and green actors are autonomous or pre-planned. Arcs in the causal diagram are annotated with $+$ and $-$ signs indicating change or effect in same direction or opposite direction respectively. As an example, the blue actor may increase situational awareness by performing patrolling operations or by setting up checkpoints. However, these operations increase the disturbance of the everyday life of civilians, which in turn has a negative effect on its opinion towards the military forces. Finally, reducing the opinion of the population decreases the population's willingness to share information, which ultimately reduces the situational awareness of the blue actor.

To complement the causal diagram in Figure 2, which describes an overview of the dynamics in the scenario, we have developed a table that focuses on the decision making aspects of the military staff following the guidelines proposed within the Job-Oriented Training (JOT) concept [4]. The purpose of the table is to identify typical mistakes that the trainee is expected to make and learn from during and after the exercise. In Table 1, we f rst specify the military staff's high-level decisions which consist of planning, monitoring/execution and assessment. The high-level decisions are concretized using critical decisions and each critical decision is associated with one or more typical mistakes or sub-optimal solutions. The table also lists trigger cues, which are used to mislead the trainee into committing mistakes, and response cues depicting the expected effects of committed mistakes.

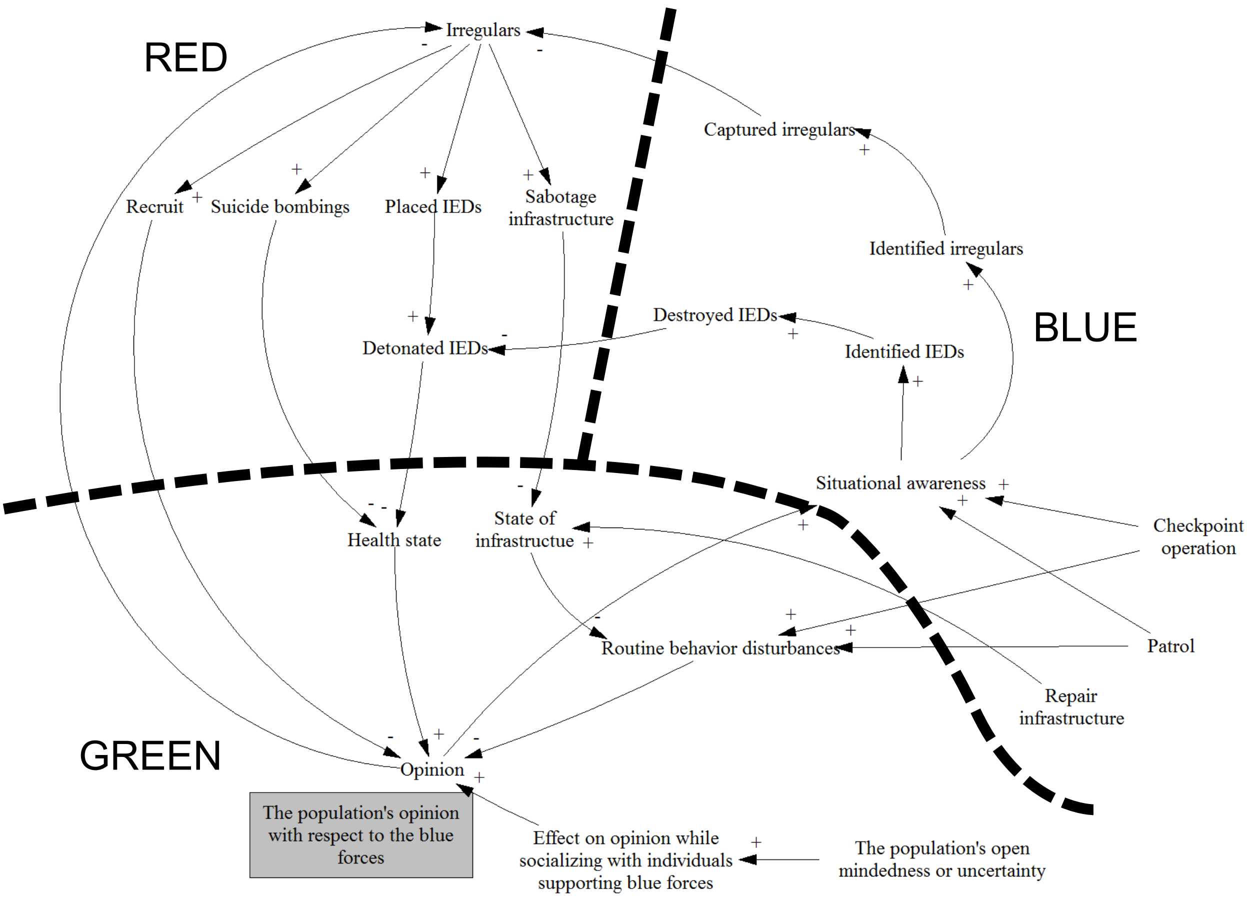


Figure 2: Causal diagram that provides an overview of the main actors, their activities, main variables and how these are affected in the scenario. The dashed curves are used to separate the causal diagram into regions representing the red, blue and green actor respectively.

Table 1: Conceptual scenario design focusing on the high-level and critical decision making of the trainee. For each critical decision a list of typical mistakes, or sub-optimal solutions, are identif ed including trigger cues (e.g. information that may lead the trainee to a sub-optimal decision) and response cues (i.e. effects of the mistake).

High level decisions	Critical decision	Typical mistakes	Trigger cue	Response cue
Plan mission	Determine geographical area or areas for the operation	Picking areas that are unknown, too large, too small, high-risk or with low information acquisition potential	Map showing roads, buildings and current state of population	-
	Determine threat-level in the geographical area of interest	Threats not taken into account when planning operation	Known IEDs or irregular forces (direct threats)	-
			Known civilian groups that supports the enemy (indirect threats)	-
	Determine if there are any planned cultural/religious events, political meetings, demonstrations, etc. in the area	Not taking special events into account when planning operation	Date and time as well as a calendar (pre-populated with events)	-
	Determine best path (e.g. shortest time/distance, low-risk and high information acquisition potential) to and from area	Path not optimal or path planned through high-threat area	Roads, buildings, known threats, population density and opinion	-
Execute mission and managing friendly forces	Monitor mission progress	Not informing troops near threat to retreat to a safe-place and await new orders	Unexpected threat reported (hostile crowd, IED, etc.)	Increased risk of being attacked; Friendly casualties; Mission failure
		Not providing backup when requested by friendly military units	Friendly forces request backup	
		Not recognizing the troops are deviating from mission orders	Troop deviate from planned patrol-route	
		Not reacting to reports of crowd formations	Unexpected crowd report	Opinion drop; Increased formation of crowds and demonstrations
	Timing	Not detecting that timing is not right	Planned progress deviates from actual progress	-
		Not re-planning the mission to meet timing constraints	-	-
Assess mission and report back to strategic leaders	Determine trends in the population	Failing to identify trends	-	-
	Determine extremist clustering	Failing to recognize extremist clusters	Geographical clustering (home, work-place) with respect to opinion	Increased polarization and segregation within the population
	Analyze and report	Failing to properly analyze and report mission results back to strategic leaders	Request from strategic leader	Misleading strategic leaders

4 IMPLEMENTATION AND EXPERIMENTAL RESULTS

In this section we describe the most important aspects of our scenario implementation starting with the modeling of the population or green actor. We f rst focused on creating the initial state of the population using the population synthesizer. We acquired demographic statistics as well as geographical information (i.e. GIS-data) representing the area of interest. The information was fed into the population synthesizer to generate a synthetic population with demographic properties (age, gender, occupation and religious belief) and geographical properties (home and work-place). The synthesizer was also used to generate the initial state with respect to the population's opinion towards the military staff and its military forces.

In the next phase we generated plans representing routine behaviors such as eating, working and sleeping for each individual in the population using POPSIM's routine behavior model. In this scenario, we f rst discretized time of day into events representing morning, noon, afternoon, evening and night. We then collected data samples representing the population's activity at these discrete events. The data was fed into the routine behavior model, which in turn f tted a probability distribution to the data. The probability distribution was then randomly sampled to generate the plans for each individual in the population.

In addition to the routine behavior we have identif ed a number of cultural events that, given that the individual is a believer, are celebrated by the individuals in the population. Cultural events are separated into minor events where individuals meet in smaller groups at distributed local sites and major events where individuals meet in larger groups at a common site. In this scenario minor events occur on a daily basis and a major event occurs at the end of day 3.

Next we modeled the opinion dynamics of the population. In this scenario opinions are updated when individuals interact one-on-one using the Deffuant model [3] and when individuals meet with each other in larger groups to, for instance, celebrate religious or cultural events using the Hegselmann-Krause (HK) model [5]. Using these models the opinion is represented by a continuous value ranging from 0 to 1 where 0 means opposing the blue actor and 1 means supporting the blue actor. An opinion value near 0.5 represents neutrality. As mentioned above we have used the population synthesizer to generate opinion values for each individual in the population. In this scenario we created a polarized initial state where there are two groups that dislike the blue forces and one group that supports the blue forces in the population.

Next we developed the domain specif c behaviors and activities of the blue and red actors. The blue actor was provided with activities to model operations such as patrolling an area, setting up temporary checkpoints and operations used to repair and sabotage for instance power or water supply in selected parts of the city. The blue actor consists of 25 agents, each representing a military unit, organized into: 5 military observations teams used for patrolling and checkpoint operations; an engineering team used to repair/sabotage city infrastructure; and a medical team used to transport and treat injured agents.

The opposing, red actor, is used in the scenario to represent direct threats that need to be considered by the blue actor when planning and executing operations. The red actor consists of 5 agents each capable of performing operations to build, place and detonate improvised explosive devices (IEDs) within the city. The red agents are also capable of repairing and sabotaging infrastructure. Furthermore, we developed a recruit activity that can be used by the red agents to actively inf uence the opinion of the population during, for instance, cultural and religious events. In addition, since the red actor is autonomous in this scenario, we created plans for each agent where the abovementioned activities are executed on a daily basis.

4.1 Experimental results

Let us now present some initial experimental results where we have created artif cial plans representing an aggressive, a moderate and a passive blue actor or trainee respectively. The aggressive plan focuses on interacting with as many civilians as possible to acquire information. It deploys all observation teams and assigns them to perform both patrolling and random checkpoint operations within the city. The moderate plan deploys fewer observation teams and limits its operations to patrolling only. Finally, the passive plan is empty and contains no operations.

In Figure 3 we use probability density plots to graphically visualize actual (i.e. simulated truth) vs. perceived (i.e. the blue actor's or the trainee's perception) civilian opinion distributions at the start of the simulation (T+0), two days into the simulation (T+2) and at the end of the simulation (T+4) using the abovementioned plans.

In Figure 3a and Figure 3b we compare the actual and perceived opinion at the start of the simulation (T+0). From Figure 3a we can see that there are two peaks to the left and one peak to the right representing the polarization or grouping of individuals discussed above. To simulate an imperfect initial perception of the opinion we have f rst limited the blue actor's population registration knowledge, representing the number of known individuals in the population, to approximately 75%. We have also added Gaussian noise to the actual opinion value of each individual in the known population. The initial perceived opinion in Figure 3b appears less alarming to the trainee as it, although a relatively large group of opposing civilians can be observed, does not express the extreme polarization of the actual opinion in Figure 3a.

At T+2, i.e. two days into the simulation, we can in Figure 3c observe that the actual opinion of the population is beginning to grow at the left-hand side and at the right-hand side as a result of neutral individuals being affected by interactions with other individuals and by the operations of the red and blue actor respectively. From Figure 3d we can see that the perceived opinion using the moderate and passive plan does not change much, compared to the initial perceived opinion in Figure 3b, whereas the aggressive plan is better at estimating the actual opinion. Using the aggressive plan the blue actor is able to detect peaks in the opinion distribution indicating that there is at least one extremist group in the population supporting the red actor. In a serious game with a real military staff this is expected to trigger discussion within the staff ultimately leading the staff to create a plan addressing the issue.

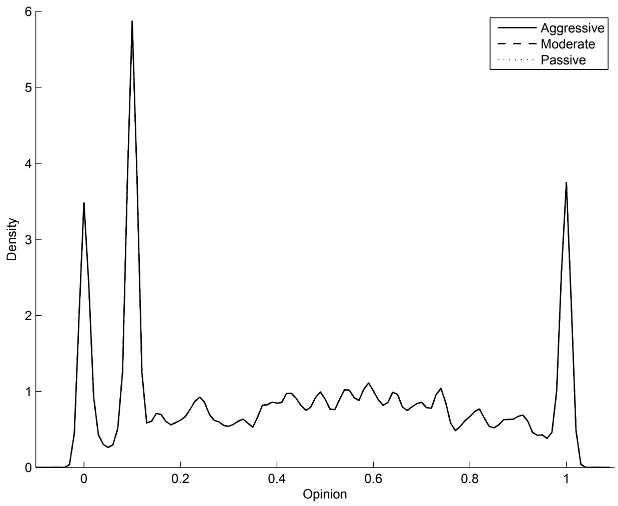
At the end of T+2 a major religious or cultural event occurs in the simulation driving the population to a shared location in the city. During this event a large number of interactions occur and as a result the opinion changes dramatically. At the end of the simulation (T+4) we can in Figure 3e observe the opinion change for each plan. In the f gure we can see that the neutral part of the population has continued to shift towards the left and right side and that the polarization effect has increased.

As we have seen in Figure 3 the manual comparison of distribution plots provides valuable insight into the dynamics of the simulation. However, to properly compare the performance of one or more trainees we have developed a set of situational awareness analysis functions that automatically compares the actual situation with the perceived situation. In Figure 4 we illustrate two relevant metrics focusing on the opinion perception (Figure 4a) and the population registration perception (Figure 4b) of the blue actor while executing the different plans. For simplicity the metrics are normalized and expressed in a percentage representing the accuracy of the perception.

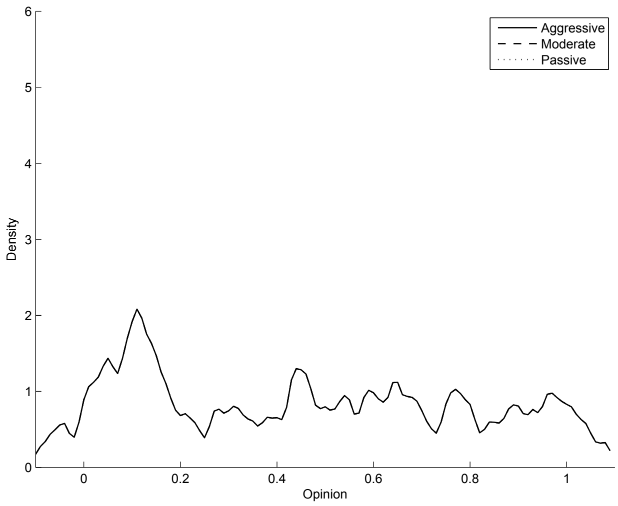
Figure 4a shows that the perceived opinion, at the start of the simulation, is 90% correct compared to the actual opinion. As the simulation progresses the perception score decreases as a result of individuals changing their opinions while the blue actor at the same time is too ineff cient to acquire up-to-date information. In this scenario the cultural events result in sudden and relatively large changes in the opinion. The effects of these events are observed in Figure 4a as sudden drops in opinion perception performance.

Similarly, in Figure 4b it is clear that the blue actor's population register, at T+0, contains approximately 75% of the individuals in the population. Furthermore, the aggressive plan is relatively eff cient at improving the population register compared to the moderate and the passive plans.

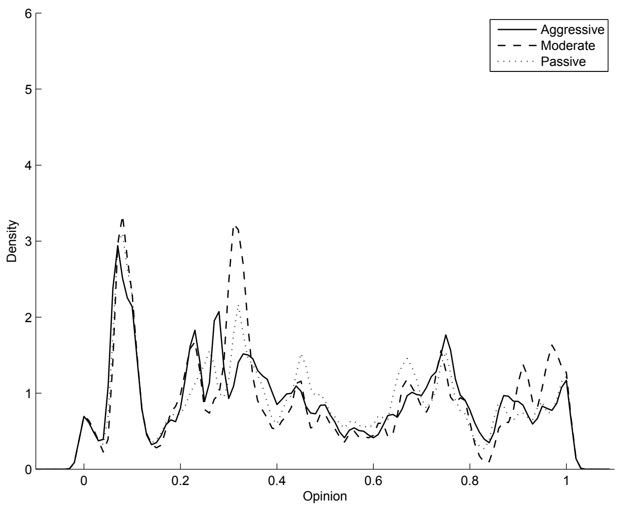
In addition to the abovementioned situational awareness functions we have also developed functions measuring trainee performance with respect to its perception of: health state of the civilians and own forces; how well infrastructure services are working; and, the location and status of threats and opposing forces.



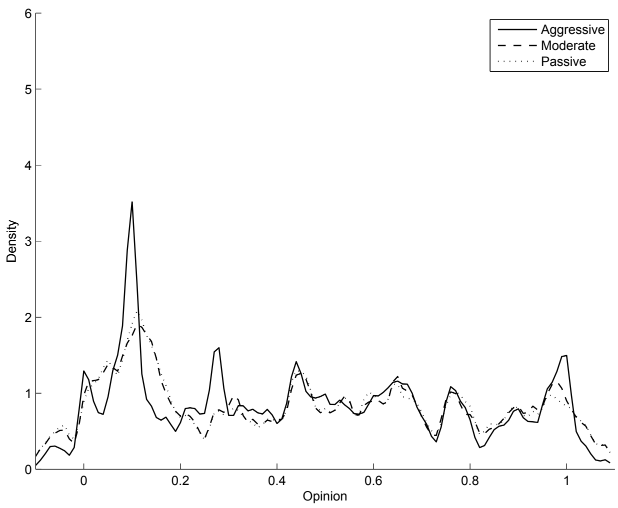
(a) Actual opinion at T+0.



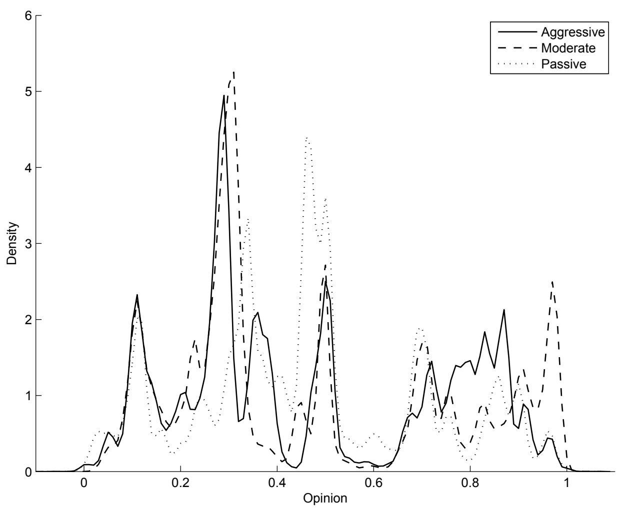
(b) Perceived opinion at T+0.



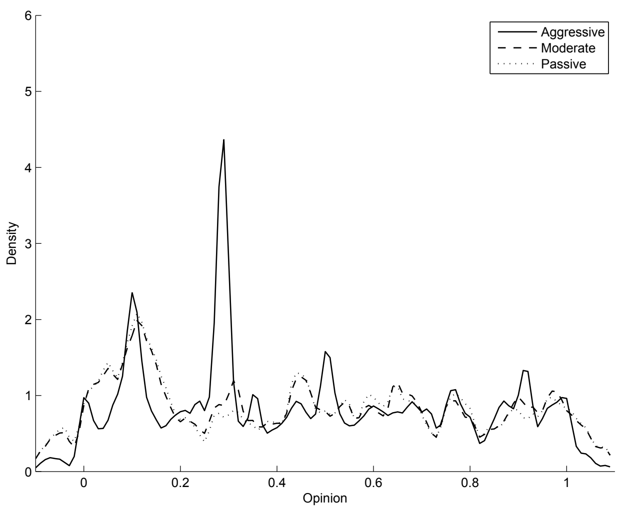
(c) Actual opinion at T+2.



(d) Perceived opinion at T+2.

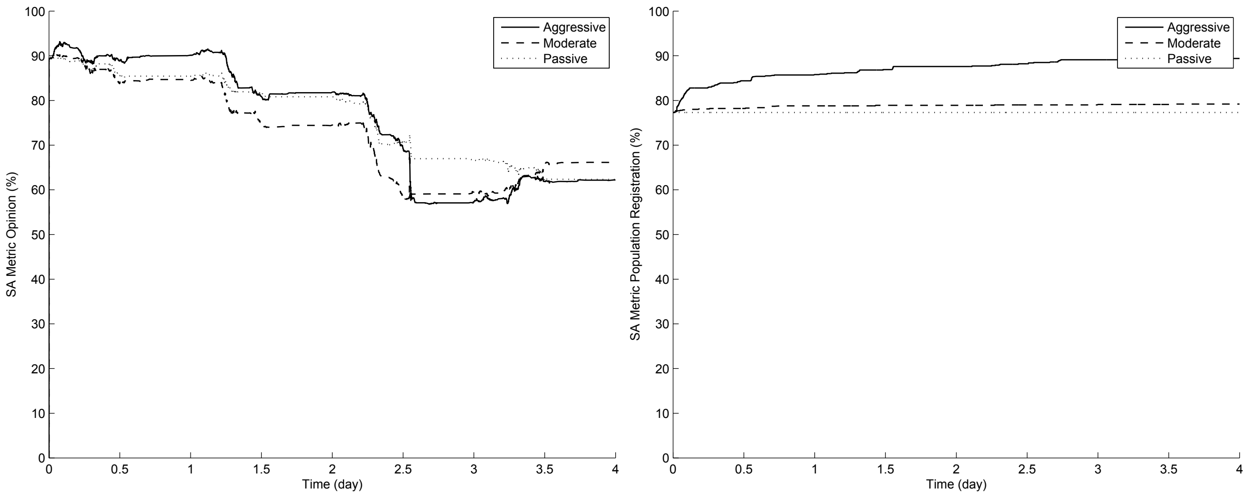


(e) Actual opinion at T+4.



(f) Perceived opinion at T+4.

Figure 3: Opinion distribution plots comparing actual vs. perceived opinion over time.



(a) Opinion metric.

(b) Population registration metric.

Figure 4: Situational awareness metrics plotted over time for all plans.

5 CONCLUSIONS

In this work we have introduced a serious gaming application targeting the training of military staffs in urban operations. The application was implemented by extending and reusing the POPSIM-platform. The main novelty of our work is that the application simulates, in addition to the tactical behaviors of own military forces and opposing forces, the behavior of the civilian population using an agent-based modeling approach. Furthermore, our application employs opinion dynamics to simulate the population's opinion and how the opinion may change over time when individual interact with each other in the simulation.

We have created a conceptual scenario design that emphasizes the importance of winning the hearts and minds of the population in urban operations. The scenario design was developed using a causal diagram expressing the dynamics of the simulation as a whole and a decision table that lists the main decisions and mistakes that the trainees are expected to make when playing the scenario.

To demonstrate the potential of our application we implemented the scenario and provided experimental results comparing three different plans representing an aggressive, a moderate and a passive trainee respectively. We implemented situational awareness metrics, measuring the accuracy of perception, that can be used to: evaluate the performance of a trainee during and after the exercise; to study the learning curve of a trainee playing the game on multiple occasions; and, to compare the performance of different trainees.

The serious gaming application presented here is a research prototype and a lot of work is required to ensure that the application is mature enough to be used in practice. Perhaps the most important future work is to thoroughly evaluate the application, including the scenario, using domain experts such as experienced military staffs and military exercise leaders. Future works also include the modeling of psychological and information operations and how they may affect the opinion of the population.

ACKNOWLEDGMENT

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