Using Evolutionary Algorithms to Improve Tactics, Techniques and Procedures in Peace Support Operations

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ABSTRACT

In this paper, we describe possible applications of evolutionary algorithms in the field of military peace support operations (PSOs), using the agent-based simulation model PAX, specifically designed for PSO [4]. PAX has been face-validated during prototypical application in the recent years and is thus considered a good basis for the exploration of further application fields.

We cover the possibilities which arise from using optimization algorithms in experiments with PAX in general as well as the need for using non-traditional optimization methods such as evolutionary algorithms, regarding the special circumstances given in a model for peace support operations.

Categories and Subject Descriptors

I.6 [**Simulation and Modeling**]: I.6.3 [Applications]; I.6.4 [Model Validation and Analysis]; I.6.5 [Model Development, Modeling Methodologies]; I.6.6 [Simulation Output Analysis]

General Terms

Algorithms, Measurement, Design, Experimentation, Human Factors.

Keywords

Peace Support Operations, Peacekeeping, Human Factors Modeling, Agent-Based Modeling, Model Robustness.

1. INTRODUCTION

The German Military Forces (Bundeswehr) have increasingly taken part in peace support operations (PSOs), mainly in Europe but also in Africa and Asia. A significant challenge to the Bundeswehr is the development of tactics, techniques and procedures (TTP) that enable military personnel to be successful in small-scale peacekeeping operations. Since the focus is on providing help and de-escalating critical situations, peace support operations, e.g. humanitarian assistance operations, can not be adequately modeled with existing combat models – which mainly focus on fighting between enemies [5].

For these reasons the high-resolution, agent-based simulation model PAX was developed in Germany by EADS in collaboration with the Department of Social Psychology of the University of Zurich and the Chair for Operations Research at the University of Passau. PAX concentrates on modeling peacekeeping aspects and incorporates a complex, empirically based psychological theory on collective aggression including human factors such as motivation, emotions or stress.

Unlike in traditional, combat-oriented models the objective functions, or measures of effectiveness (MOEs), in PAX include goals such as "ensuring safety in the soldiers' area of responsibility" and simultaneously ensuring their own safety and using as little force as possible. These concurrent goals make PAX – just like PSOs in general – inherently multi-objective. Table 1 shows some of the MOEs used when examining a checkpoint scenario – the goal of keeping own engagements at a low level may, for example, conflict with the goal of keeping the situation calm.

Table 1. Some of the main MOEs considered in the scenario "checkpoint" modeled with PAX

MOE	Optimization
Overall escalation (keeping the situation calm) as a weighted function of the number of attacks and threatening actions performed by civilians	MIN
Number of military engagements	MIN
Number of people that crossed the checkpoint	MAX
Positive attitude of population at the end of the simulation (measurement of long-term effects)	MAX

Scientific use of PAX in the past years in the US Marine Corps-lead "International Project Albert"[1] (see [6]) as well as at the Naval Postgraduate School in Monterey, CA (see [8], for example) has shown that this model has a high degree of relevance for modeling certain aspects and scenarios of peace support stability operations especially in the context of humanitarian assistance and nation building, e.g. in vignettes such

[1] http://www.projectalbert.org

as food distribution, elections or checkpoints. Since its application has so far mainly been focused on analysis and experimentation it seems promising to investigate the capabilities of PAX in the area of customizing soldiers' TTPs or even providing decision support.

Therefore, optimization methods are required which provide a good probability for a close-to-optimal solution while being able to handle drawbacks such as multiple objectives or non-linearity, for example. These are inevitably implied when modeling the complex facets of a PSO, such as human factors or the evolvement of collective aggression, as is done in PAX.

2. PRESENT WORK WITH PAX

The US Marine Corps Warfighting Laboratory has initiated the "International Project Albert" to address problems and phenomena that could not be sufficiently examined so far with existing modeling methodologies. One of the key methods developed and used within Project Albert is *data farming* [1] – a meta-technique that applies high-performance computing to experimenting with simulation models in order to examine and understand the landscape of potential simulated outcomes, thus providing an overview of the model and scenario behavior, often yielding surprises and potential options overseen before.

Data farming has heavily been applied in the experiments conducted with PAX so far, providing detailed insight into scenario-related dynamics of the operations and the model behavior, thus enabling analysts and developers alike to face-validate and improve the model. Most significantly, however, the extensive experiments conducted so far have frequently led to unexpected simulation results. Many of these results, which initially seemed to be peculiar, proved not to be due to the model's poor representation of reality, but rather due to the analysts' limited imagination concerning possible outcomes in a PSO mission.

Our main objectives in working with PAX have hitherto been:

- Face-validation of the model
- Finding non-linearities and coevolving effects
- Understanding the special circumstances of PSO
- Supporting expert-driven analysis and discussion

The data farming method has provided us with the means to look at different PSO scenarios in a holistic sense in that we can analyze the results of experiments with thousands of simulation runs instead of only looking at single runs, or point estimates.

2.1 Examining Fitness Landscapes

Looking at fitness landscapes as the one shown in Figure 1 has proved to be an excellent way of getting an idea of the dynamics of the scenario vignette under examination. These plots of a two-dimensional fitness function of an experiment (which may also be a projection of a much larger search space on two parameters) are easy to understand yet can be powerful in their expressiveness. Fitness landscapes give a visual impression of the influence of the varied parameters on the chosen MOEs while showing surprises and, to some extent, even pointing to non-linearities. Their strength during the analysis process lies in their simplicity and clearness.

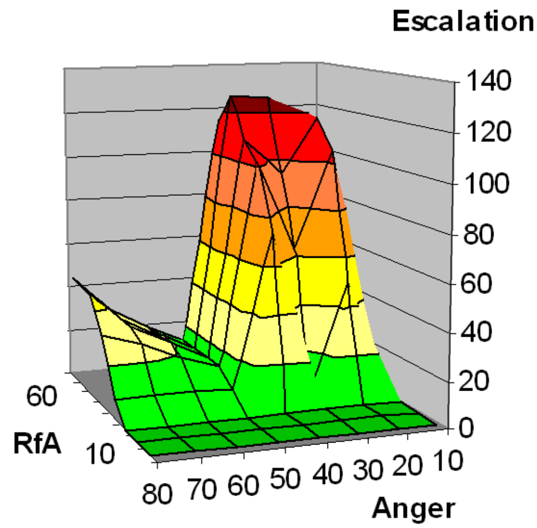

Figure 1. Two-dimensional fitness landscape for the MOE "Escalation" over the model parameters "Readiness for Aggression" and "Anger" of a Civilian group

2.2 Using Regression Analysis

The large amount of data which can be produced in a reasonable amount of time by using the data farming technique on high-performance computer clusters provides a good statistical basis for different kinds of regression analyses, from regression trees to complex fit models, enabling us to find relationships among our input parameters (i.e. the predictors) such as quadratic effects, outliers and coevolution. The observations have also shown that the response of the model to different scenario and parameter setups, despite not being random, is hardly predictable. This particularly applies for coevolving effects resulting from different agents being closely dependent on each others' reactions and behavior in the model, which can make the MOEs react heavily to even slight changes in the input parameters.

2.3 Current Research

With a better understanding of at least some of the crucial factors in the vast complexity of PSO scenarios, a reasonable next step seems to be to focus on those factors that the peacekeeping forces can really influence in a real-world military operation[2]. Thus, besides advancing in model development to improve the stability and expressiveness of PAX the main objective at present and in the near future is to vary the soldiers' tactics, techniques and procedures (TTPs) to enhance the mission effectiveness and robustness of the own forces' behavior.

[2] These factors, of course, are not necessarily more crucial than lots of the factors our troops have to cope with despite not being able to influence them during an operation at least in the short term, such as personality, norms, experience or religious motivation of the people encountered or major terrain aspects.

3. EVOLUTIONARY ALGORITHMS APPROACH

Optimizing soldiers' TTPs as well as the initial scenario setup[3] is not a trivial task with influences involving human factors, an asymmetric enemy and a multi-objective mission as seen in PSOs. Therefore, an optimization method has to be found that is able to handle these particularities while being sufficiently effective in terms of runtime and the quality of the results.

3.1 Problems with Traditional Optimization Algorithms

As mentioned before, some of the characteristics specific to peacekeeping missions and the involvement of human factors confront us with problems when analyzing a PSO simulation model in the pursuit of optimization, including:

- A multi-objective mission
- Non-linearity of the MOEs
- Multi-modality of some MOEs

Most of the traditional optimization methods, including the complex or Rosenbrock algorithms (cp. [7]), are unable to cope with some or all of these issues, at least in special cases.

At least some of them, however, can be addressed with the help of genetic and evolutionary algorithms. Moreover, as a basic precondition, we have got a fair amount of computational power available (EADS Deutschland GmbH operates a data farming cluster in Germany on behalf of the German Bundeswehr), as well as the means of easily implementing different evolutionary algorithms and strategies for use on a computer cluster, thanks to the data farming environment described in [3].

3.2 Possible Algorithms and Applications

3.2.1 Algorithm Selection

In their broad applicability evolutionary algorithms appear to be a manifest solution. Given a sensible selection of the algorithm and its parameters they usually promise to cope well with non-linear as well as multi-modal fitness functions.

One of the main concerns in the field of PSOs, the inherently multi-objective mission with competing fitness functions, however, requires a specialized algorithm. Thus we are planning to customize one of the existing multiobjective genetic algorithms as described in [2], for example, and incorporate it into our present data farming environment.

3.2.2 Applications

Once we are able to calculate a pareto-optimal set of solutions in a reasonable amount of time for any given scenario, the path will be paved towards a decision support tool for certain aspects of PSOs. Having so far been rather limited to making tendency predictions about possible outcomes of the simulation with a given situation and chosen TTPs, it will then be possible to perform a goal-oriented analysis of the parameter space and thus get a robust modeling environment, providing quick and reliable propositions for the optimal behavior in the current situation under the assumed preconditions.

Note that this "optimal behavior", being represented by those parameter combinations in the located pareto-optimal set, does not necessarily refer to specific model elements, such as the soldiers' or blue forces' behavior. Therefore, application ranges from decision support for the blue forces in a PSO to red-teaming and wargaming. Moreover, we expect to gain a better robustness in the sense of enhancing the own forces' variety of potential TTPs by completing our analysis repertoire with means to do experiments with different weightings of the MOEs and examining possible "extreme" outcomes (by doing a best case or worst case analysis).

4. CONCLUSION AND FUTURE WORK

PAX is considered a useful simulation model for modeling a variety of aspects of peace support operations. It models human factors on the civilian and the soldier side and features a complex social-psychological model of the evolvement of collective aggression. Its application so far has shown its potential on the analytical level for concept development and experimentation and partially also for the development and planning of TTPs.

Using genetic algorithms integrated into the data farming environment presented in [3] may pave the way for a more immediate application of PSO model experimentation. In addition to the capability of planning TTPs after the analysis of extensive experiments, this environment could generate robust and reliable answers and decisions directly during the course of events, for example in a wargaming situation. In conclusion, this at least indicates a perspective of providing decision support in the operational analysis and planning phase. Moreover, since human factors such as stress on the soldier side are modeled in PAX, this capability would not be limited to TTPs alone, but could be expanded into the area of mission training procedures, just to give an example.

Another area of application in the future may be training and education. The usage of PAX as an interactive tool for leadership training has been previously under discussion and the feasibility of this approach in principle has been shown in a prototype. The credibility and usability, however, might be improved if the trainee could, for example, be confronted with worst case scenarios that might result from his decisions or, on the contrary, be shown alternate decisions that could have lead to a better course of actions.

5. ACKNOWLEDGMENTS

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[3] again, to the extent to which it could be influenced in a real world mission

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