



## **EXPERIMENTS WITH PAX**

A Quick Guide

(Version: July 06, 2005)

Including a case study from the  
**10<sup>th</sup> Project Albert International Workshop**

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## **1 Overview**

This document gives

- a quick overview about the agent-based simulation model PAX,
- its applications and how to conduct experiments with PAX and analyze the results and
- where the focus is on experiments within the US Marine Corps' Project Albert or at least using the Project Albert tools.

The next chapter introduces the model itself, its history and applications. Following that, the process of data farming with the model is described before a case study in chapter 4 describes the experiments conducted during the 10<sup>th</sup> Project Albert International Workshop (PAIW10) in Stockholm, Sweden, by the "Peace Support Operations" (PSO) working group.

## **2 PAX – A Model Designed for Peace Support Operations**

### **2.1 Motivation and History**

PAX is a prototypical agent-based model for Peace Support Operations (PSO). Current version is 2.1 (May 2005).

It was developed because of the insufficiency of existing, attrition-oriented combat models for modeling peace support operations, which are becoming more and more important for most armies in the world. Therefore, EADS Deutschland has developed PAX on initiation of and funded by the "German Army Training, Doctrine and Army Development Command" and the "Bundeswehr Transformation Center".

Its development started in 2002. The model has since then extensively been improved and expanded, broadening the range of its applications as well as stabilizing the model behavior and thus making it a useful tool for modeling aspects of peace support operations. The German army has made PAX available for usage within the international Project Albert community.

### **2.2 Model Description**

PAX is an agent-based model concentrating on modeling certain aspects of peace keeping operations. At the moment the main effort is on modeling different civilian crowds including leaders and communication between the soldiers, civilian leaders<sup>1</sup> and the remaining members of the crowd. It enables the user to investigate the effects of different actions (tactics, techniques and procedures) of the military under certain configurable conditions and different behavior of the civilians.

PAX focuses on modeling the emergence of aggressive behavior among a group of civilians which is why the civilian agents are modeled in much more detail than the military agents, which currently act purely reactively and in an ideal way according to a certain set of rules (in the following text called "rule set"). Probably the most important factor in the model therefore is aggression or escalation since the

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<sup>1</sup> So far, work with PAX has mainly focused on examining scenarios with just one civilian leader, although more than one leader is supported.

main objective in any peace support operation is to deescalate the situation whenever possible<sup>2</sup>. Hence the model's measures of effectiveness (MoEs) include, but are not limited to:

- Escalation among all agents, caused by civilians or soldiers, caused by a certain civilian group or appearing in a certain area (e.g., in an election scenario, the election area)
- The number of votes performed or supply packages distributed (depending on the type of PSO mission looked at)
- Average fear / anger / readiness for aggression among the civilians or certain civilian groups

These factors and the psychological model behind them make PAX more suitable for the analysis of peace support operations than most common, attrition-based combat models.



*Figure 1: Typical situations in a peace support operation for ensuring elections*

### **3 Data Farming with PAX**

#### **3.1 A "Recipe" for Conducting Experiments**

In principle our proposed way of conducting experiments can be divided into the following steps:

1. Select a high-level scenario (such as "food distribution", "elections" or "controlling a checkpoint")
2. Build a base case scenario matching the high level scenario selected in step 1.
3. Find the most significant parameters using a design (like the NOLH design) and fitting a regression model to the results
4. Decide which parameters to data farm (using the parameters found in step 3 and any additional parameters that you want to vary)
5. Build a study and send the runs to a computing cluster (or a local machine)
6. Analyze the results using statistical tools and methods like regression models and fitness landscapes
7. Optionally examine single simulation runs in more detail using the PAX animation

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<sup>2</sup> There are various reasons for this, ranging from immediate effects (trying to minimize own losses) to long-term or side effects when thinking about the people's attitude and behavior towards the PSO force on subsequent missions in the same area.

Of course some of these steps or the whole process can be repeated in order to fit your personal requirements. Note that data farming usually is an iterative process of repeating experiments under altered conditions having analyzed previous experiments.

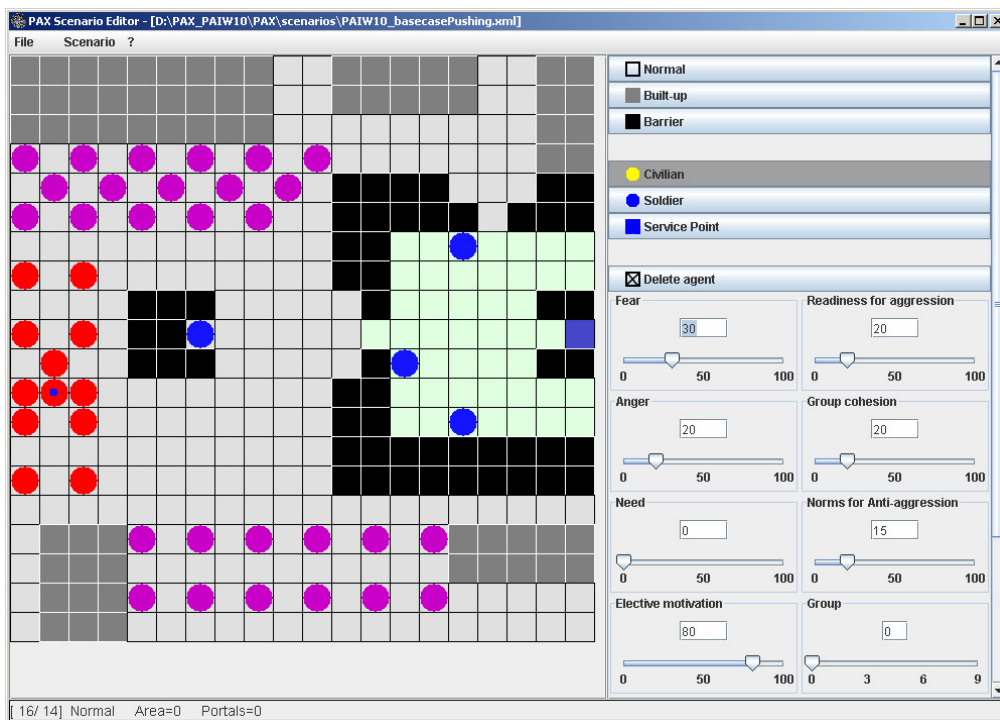
Please see Dr. Gary E. Horne's text "Beyond Point Estimates: Operational Synthesis and Data Farming" in "Maneuver Warfare Science 2001" p. 1-7 as basic literature about Data Farming.

### **3.2 Using PAX with the Project Albert Data Farming Environment**

Even within Project Albert there is more than one way of sending a study to a computer cluster and analyzing the results. The preferred way for PAX and some alternatives will be described in this section.

#### **3.2.1 Setting up a Scenario**

This is done using the *PAX Scenario Editor* shipping with PAX, which is shown in Figure 2. Its usage is described in more detail in the HTML online help.



*Figure 2: The PAX Scenario Editor*

Once you have created a scenario file<sup>3</sup> you can proceed with building an experiment as described in the next section.

<sup>3</sup> Scenario files are stored in XML format.

### 3.2.2 Defining and Conducting an Experiment

Defining an experiment is just as easy as setting up a scenario. Figure 3 shows the *PAX Experiment Editor* which can be used for this purpose. It is intentionally kept very similar to the scenario editor in its appearance and user interface. The experiment editor creates studies that can be used with the Project Albert tool *OldMcData – The Data Farmer*. These studies can either be sent to a computer cluster or can be executed on a local machine, depending on what is specified in the study description you create. PAX is currently only available on Windows so sending runs to Linux clusters is not supported in the current PAX version 2.1.

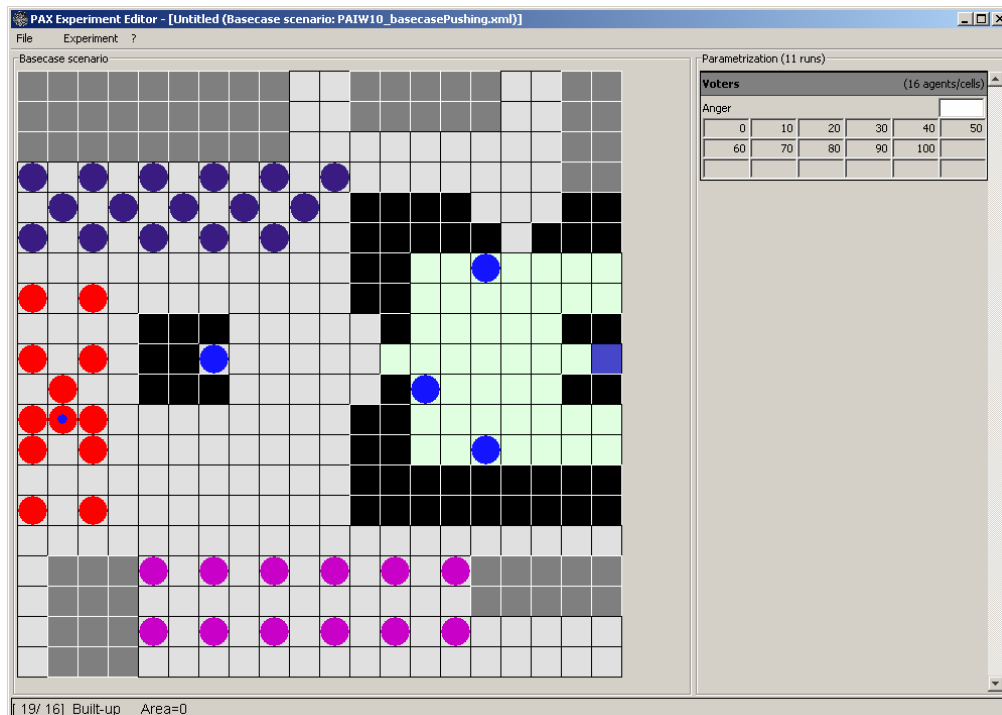


Figure 3: The PAX Experiment Editor

An alternative to using the PAX Experiment Editor would be using the Project Albert Tiller which does not, however, provide you with a graphical view of the scenario when setting up your study. It is also not usable with PAX yet but as a supplement will be in the future since it is generally more flexible and allows to specify more settings than the PAX experiment editor.

Afterwards, the experiment is sent to the desired resource using Project Albert's command line tool *OldMcData*. Since this software is still experimental and keeps changing, the cooperation of the experiment editor and *OldMcData* can sometimes cause problems<sup>4</sup>. The command line call for running *OldMcData* is displayed in Figure 4, also showing that it is not suited for inexperienced users.

<sup>4</sup> In such a case please contact the Project Albert team.

```

C:\WINDOWS\System32\cmd.exe - oldmcdata.start.bat C:\OldMcData.new\test\PAXTest Wahlexperiment_Zufall.xml
C:\OldMcData.new>oldmcdata.start.bat C:\OldMcData.new\test\PAXTest Wahlexperiment_Zufall.xml
C:\OldMcData.new>set OMD_LIB=C:\oldmcdata.new\Lib\
C:\OldMcData.new>set JADE=C:\oldmcdata.new\Lib\jade.jar;C:\oldmcdata.new\Lib\jadeTools.jar;C:\oldmcdata.new\Lib\jadeTools.jar
C:\OldMcData.new>set COLT=C:\oldmcdata.new\Lib\colt.jar
C:\OldMcData.new>set PES=C:\oldmcdata.new\Lib\PES.jar
C:\OldMcData.new>set XALAN=C:\oldmcdata.new\Lib\xalan.jar
C:\OldMcData.new>REM set DOM4J=C:\oldmcdata.new\Lib\dom4j-full.jar
C:\OldMcData.new>set DOM4J=C:\oldmcdata.new\Lib\dom4j-1.5.jar;C:\oldmcdata.new\Lib\jaxen-1.1-beta-4.jar
C:\OldMcData.new>set NALEX=C:\oldmcdata.new\Lib\nalex1.0-20031119b306.jar
C:\OldMcData.new>REM set OMD=C:\oldmcdata.new\bin
C:\OldMcData.new>set OMD=C:\oldmcdata.new\Lib\oldmcdata1.0-20040412b52.jar
C:\OldMcData.new>REM set OMD=C:\oldmcdata.new\Lib\oldmcdata1.0-20040325b48.jar
C:\OldMcData.new>set CLASSPATH=.;C:\oldmcdata.new\Lib\jade.jar;C:\oldmcdata.new\Lib\jadeTools.jar;C:\oldmcdata.new\Lib\colt.jar;C:\oldmcdata.new\Lib\PES.jar;C:\oldmcdata.new\Lib\dom4j-1.5.jar;C:\oldmcdata.new\Lib\jaxen-1.1-beta-4.jar;C:\oldmcdata.new\Lib\xalan.jar;C:\oldmcdata.new\Lib\nalex1.0-20031119b306.jar;C:\oldmcdata.new\Lib\oldmcdata1.0-20040412b52.jar
C:\OldMcData.new>java jade.Boot -port 1200 starter:oldmcdata.agents.StarterAgent(C:\OldMcData.new\test\PAXTest Wahlexperiment_Zufall.xml oldmcdata.config.xml)
This is JADE 2.5 - 2002/02/05 14:01:24
downloaded in Open Source, under LGPL restrictions,
at http://jade.cse.lt.it/

```

Figure 4: The command line tool OldMcData

Since using the experiment editor and OldMcData requires a lot of manual work you may alternatively want to use the web interface provided by Project Albert. This, however, has various other drawbacks and cannot currently be used with the latest version of PAX since the web interface only supports sending studies to the Linux cluster at the Maui High Performance Computer Center (MHPCC) instead of a Windows cluster. The PAX version installed at the MHPCC (1.6) is meanwhile outdated, since the current version is 2.1 (May 2005).

### 3.3 Analysis of PAX Experiments

There are several ways of analyzing the results from experiments conducted with PAX. Thus, you are free to use your preferred statistical tool as well as the method that seems most adequate to you. Statistical tools recommended by and used within Project Albert include the commercial tools *JMP 5.1* and *S+* or the free packages *R* and *Weka*.

The Project Albert PSO working group usually conducts the analysis using *JMP 5.1* and the PAX visualization tool. This tool allows the creation of fitness landscapes like the ones shown in Figure 9 on page 14. Besides those fitness landscapes, the group typically uses regression trees and common regression models (also called "fit models") as seen in Figure 6 on page 11. However, the main application has so far been to study the fitness landscapes and scan them for surprising effects which can then be retraced by rerunning single simulation runs and having a closer look at the course of the simulation.

### 3.4 Experiments Using Different Designs

As mentioned in the "recipe" in section 3.1, the classic procedure for conducting experiments is to start off with an experimental design that allows for a first analysis of the scenario and its significant factors before repeating the experiment with a fully factorial design and a reduced number of these factors



with high significance to get a clearer picture of the impact of these factors on the model behavior. Within Project Albert the Nearly Orthogonal Latin Hypercube (NOLH) design of the Naval Postgraduate School (NPS) in Monterey is typically used for this purpose since it provides an equally space-filling set of design points being nearly orthogonal (and thus sufficiently independent for analysis). As a first approximation, it provides insight into:

- the most significant and sensitive parameters of the scenario
- correlation between parameters
- quadratic or higher-dimensional effects of parameters
- thresholds and limits of the model

This preliminary study is then followed by an experiment using a fully factorial design to gain more insight into the model behavior and especially in the impact of the most significant model parameters with regard to the examined scenario.

## **4 Case Study: Syndicate "Peace Support Operations" at PAIW 10**

### **4.1 Overview**

The following paragraph introduces the PSO syndicate's main objectives for PAIW10, followed by a list of participants. Paragraph 4.4 describes the experiments conducted during the week in chronological order and the conclusions that were drawn. Notice that the proceeding is essentially that of the "recipe" described in chapter 3. The conclusions of the group's work are summarized in paragraph 4.5.

### **4.2 Objectives**

Led by the Bundeswehr Transformation Center, CD & E Division, represented by Major Erlenbruch, the findings of the previous workshops were supposed to be further inspected and the model enhancements new to PAX 2.1 be applied and evaluated by face validation of all group members, especially those with military background and expertise. Another issue was using the data farming capabilities of PAX to have experiments run on the Windows cluster of the Defense Science Organization (DSO) in Singapore.

Examining the stochastic elements of PAX reviewed after the last workshop PAIW9 played another important role in validating their efficient implementation and usefulness as well as comparing the stochastic model to the purely deterministic model with regard to plausibility and validity.

The group also highly profited from the international cooperation in working with PAX, providing new perspectives, useful remarks and criticism in a very constructive atmosphere. In particular this was thanks to the participation of Suat Kursat Gun, 1st Lt in the Turkish Army and currently NPS student working with PAX, Chwee Seng Choo of the Defense Science Organization Singapore and Jim Girard from Thinking Metal LLC, USA.

To be able to compare the results with those of previous workshops, the group mainly examined the "Elections" vignette as in PAIW9. The soldiers' mission of observing the election process is multi-objective, as is inherent with most peace support operations, their main objectives being:





- giving every civilian the chance to cast a vote
- minimizing own losses
- preventing violence
  - performed by other civilians as soon as possible
  - on the soldiers' side whenever and wherever possible in consideration of the other objectives

In particular the goals and topics of the PSO group can be characterized as follows:

- Face validation of the model and its enhancements made since PAIW9, particularly:
  - the reviewed stochastic elements of PAX
  - the enhanced movement planning including the agents' possibility to jostle
  - the new group- and area-specific MoEs (e.g. measuring escalation in certain areas)
- Executing different experiments, using both NOLH designs and a data farming cluster:
  - election scenario with and without jostling as well as with and without stochastics
  - scenario examined by the participating NPS student
- Identifying needs and ideas for future development and enhancement of PAX

### **4.3 Participants**

- Major Thomas Erlenbruch (ZTransfBw, Ber CD&E, Germany, Team leader)
- Gunther Schwarz (EADS Deutschland, Technical leader)
- Thorsten Lampe (EADS Deutschland, Technical co-leader)
- COL (GS) Otto Reiner (HA I 1 (4), Germany)
- Chwee Seng Choo (Defense Science Organization, Singapore)
- Jim Girard (Thinking Metal LLC, USA)
- 1<sup>st</sup> Lt Kursat Gun (Naval Postgraduate School Monterey / Turkish Army, Turkey)

### **4.4 Experiments**

The experiments are principally described in the order in which they were conducted during the workshop. The PAX version used was 2.1 as of May 2005.

#### ***4.4.1 Scenario "Elections"***

The base case scenario that was used in all of the experiments described in the following sections 4.4.2 to 4.4.4 is shown in Figure 5.

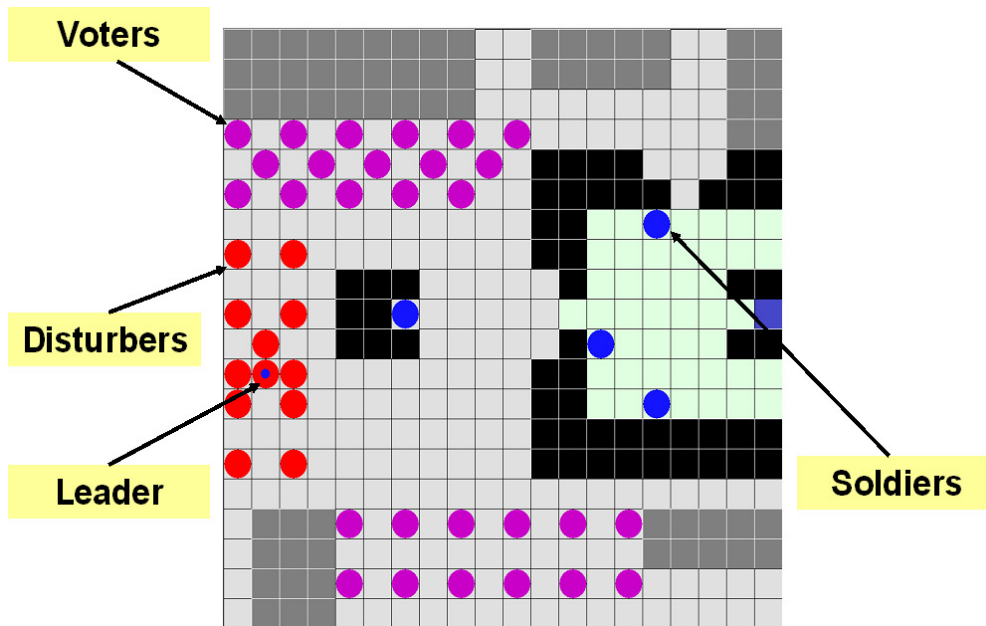


Figure 5: PAIW10 base case scenario

The scenario is set up with the following agents:

- 28 civilians willing to vote
- 12 angry civilians – interpreted as disturbers of the election, one of them being characterized as a leader
- 2 military admission controls guarding the entrance and exit of the election area, respectively
- 2 military "reserves", one as patrol close to the entrance, the other as a real reserve inside the election area
- 1 polling booth inside the election area

#### 4.4.2 Using the NOLH Design to Identify the Most Significant Parameters

To start off a preliminary study was made using an *NOLH-Design*<sup>5</sup> with 129 design points (i.e. simulation runs) in order to identify the two most significant model parameters with regard to the most important *MOE*<sup>6</sup> "Aggregated Escalation"<sup>7</sup> for use in subsequent experiments. By means of the statistical tool *JMP IN* and especially its regression trees (cp. Figure 6) the initial readiness for aggression of the voter group and the personality constant for the dynamics of fear of the voters were identified as being the most significant model parameters.

<sup>5</sup> Nearly Orthogonal Latin Hypercube Design

<sup>6</sup> MOE: Measure of Effectiveness

<sup>7</sup> The "Aggregated Escalation" is defined as a weighted sum of all attacking or threatening actions taken by any civilian during the course of the simulation.

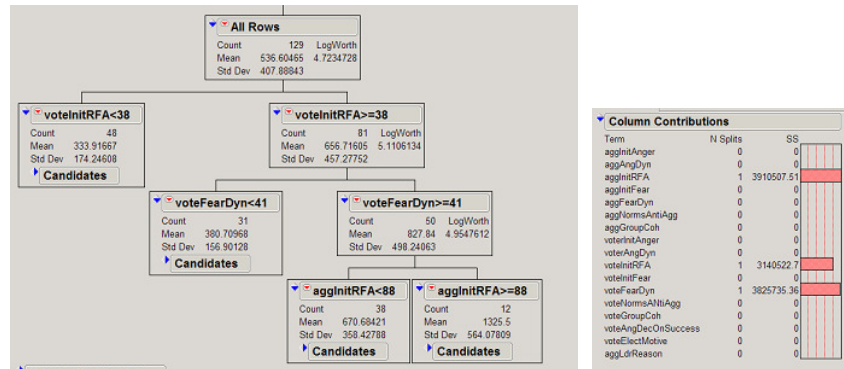


Figure 6: Regression tree to the MOE "Aggregated Escalation"

As the group noticed that the following split along the axis of the disturbers' readiness for aggression yielded yet another considerable difference in the resulting half spaces this parameter was also taken into account in the main experiment described in the next section. For the sake of a clear visualization in the form of the well-known fitness landscapes, however, the only values looked at for this parameter were 70 (below the split boundary) and 95 (above the split boundary) so that the number of fitness landscapes to consider was only doubled.

#### 4.4.3 Examining the Stochastic Effects in PAX

Pursuant to the insights from the experiments done with the NOLH design as described in the previous section four succeeding experiments were set up (two of which were sent to the DSO's Windows cluster in Singapore):

Experiment	Model	Disturbers' readiness for aggr.	#Replicates	#Runs	Execution
01_a	stochastic	70	30	10890	DSO Singapore
01_b	stochastic	95	30	10890	DSO Singapore
02_a	purely deterministic	70	1	363	local (Notebook)
02_b	purely deterministic	95	1	363	local (Notebook)

The following parameters were varied therein:

- Initial **readiness for aggression** of the voters: [0, 100], step size 10
- **Personality constant for fear** of the voters: [0, 100], step size 10
- **Rule set** of all soldiers: 1, 4, 6 (i.e. "PSO Manual", "Gandhi" and "Zero Tolerance")

In the stochastic case, stochastics in both model initialization and model dynamics were used and the parameters were varied as follows:

- Initialization:
  - Variables fear, anger and readiness for aggression
  - Standard deviation 2.0
- Model dynamics:

- o Variables fear anger and readiness for aggression
- o Standard deviation 1.0

The new concept of jostling was used throughout all runs since comparing single simulation runs had shown the day before that this makes the simulation more realistic (cf. section 4.4.4).

The group members' expectations as to the result of the experiments (measured in terms of the MoEs "Aggregated Escalation" and "Number of Votes Cast") were recorded before the experiment was conducted:<sup>8</sup>

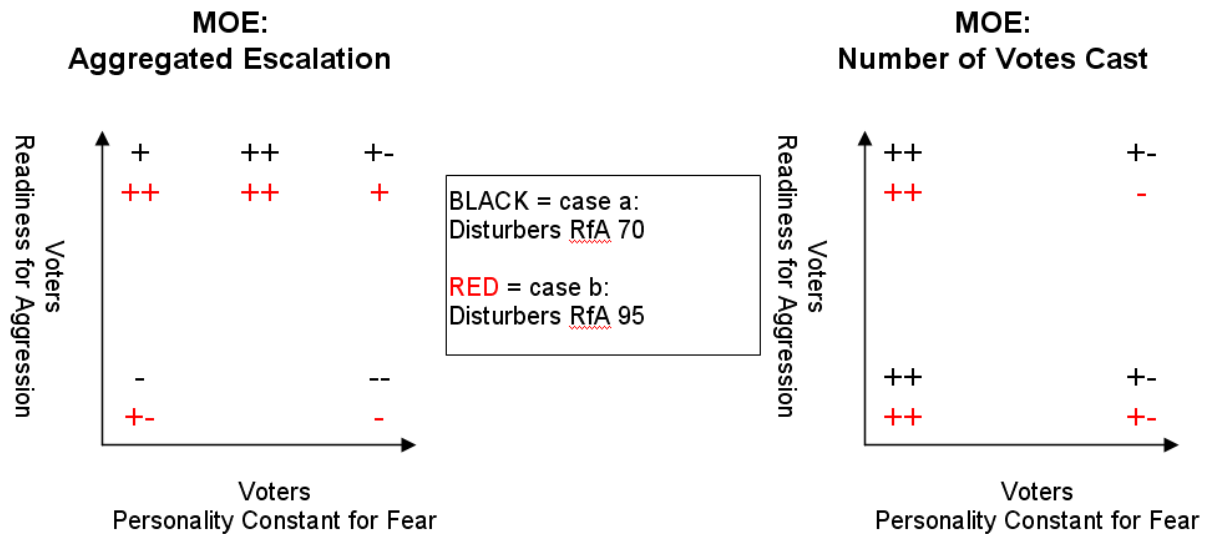


Figure 7: Expectation of the group members as to the outcome of the experiment<sup>9</sup>

Once the simulation runs had been done the actual outcome of the experiment was compared to the expectation using the fitness landscapes provided by the PAX visualization tool. Special attention was paid to surprising discrepancies which were then validated by looking at the corresponding runs.

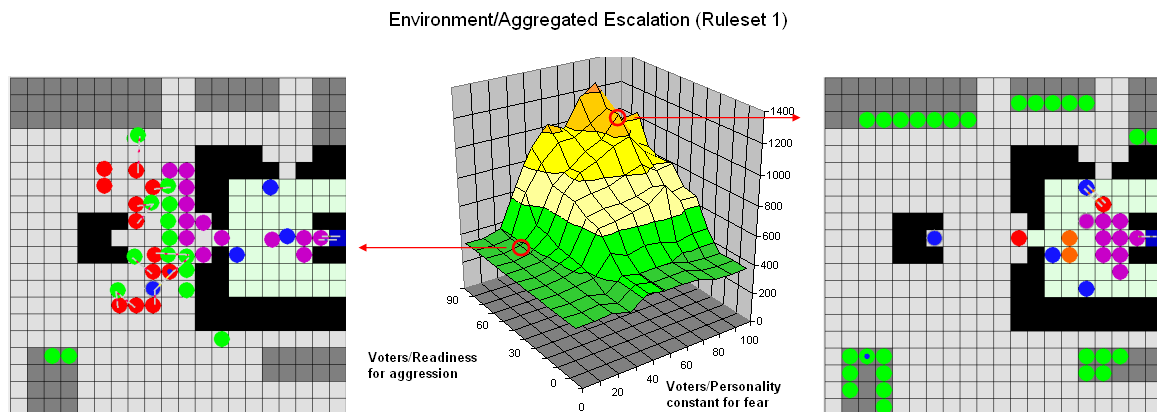


Figure 8: Fitness landscape regarding the MOE "Aggregated Escalation" in case a with two snap-shots of the examined single simulation runs

<sup>8</sup> The expected value of the MOE is displayed from very low to very high (using the symbols --, -, +, ++).

<sup>9</sup> "++": very high value expected ; "+": high value expected ; "+-": average value expected ; "-" low value expected ; "--": very low value expected ; "RfA": Initial Readiness for Aggression

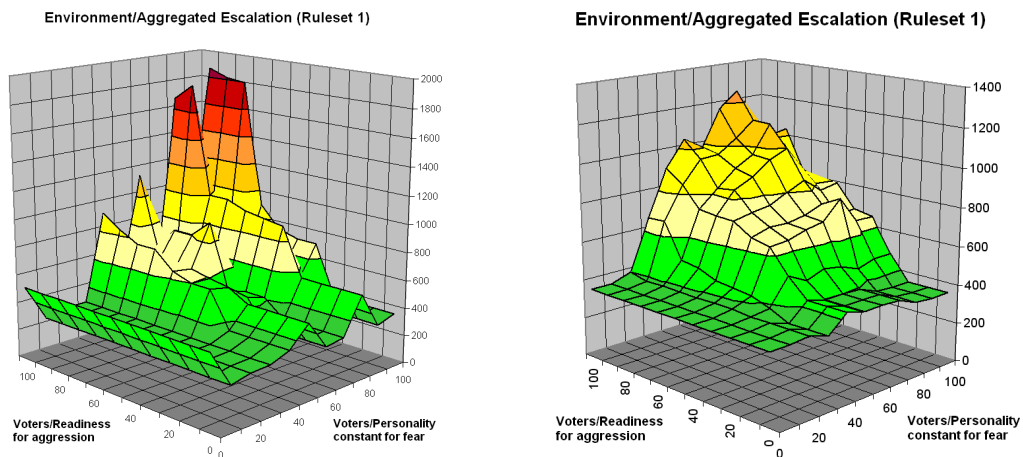
Figure 8 displays the fitness landscape of the MOE "Aggregated Escalation" in case a (disturbers' readiness for aggression of 70). Although having a certain similarity to the expectation, it also shows some obvious differences, which is why some simulation runs were examined in their detailed course. Two of them are also shown in Figure 8:

- Voters' personality constant for fear 20 (left picture): The situation shown occurs shortly after the simulation has started (T = 17). The high escalation at the beginning forces the reserves to immediately interfere, causing the majority of the civilians to back off as a result. The low personality constant for fear leads to these civilians' hardly ever returning onto the scene so that as a consequence hardly any aggression occurs.
- Voters' personality constant for fear 80 (right picture): This picture shows the situation at point in time T = 50. Due to the high value of the personality constant the civilians' fear quickly goes down again such that small groups of civilians keep returning to the scene and into the election area in order to vote or just to disturb. This leads to a higher overall escalation accumulated over the course of the simulation, both inside and outside the election area.

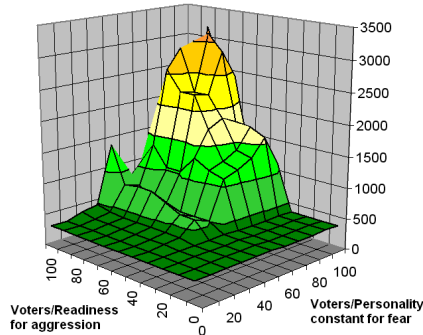
Therefore, the model behavior was generally accepted as being plausible. More simulation runs for case b (disturbers' readiness for aggression of 95) showed a particularly high escalation inside the election area. Since this is to be avoided whenever possible in a real world mission the escalation in certain areas should be observed more closely in the future.

Another main issue had been the comparison of the stochastic model with the deterministic model. Once again, the group observed the problem of a "cloned behavior" of all civilians in the deterministic case in that the civilians suddenly change their behavior all at once due to the crossing of a certain threshold. These effects can lead to a less realistic model behavior.

In comparison the model including stochastic elements led to a more realistic model behavior and, naturally, smoothed the fitness landscapes of the different MoEs. Figure 9 shows an example, also illustrating the partially non-intuitive model behavior of the deterministic model, especially visible for case "a" (upper part).



Environment/Aggregated Escalation (Ruleset 1)



Environment/Aggregated Escalation (Ruleset 1)

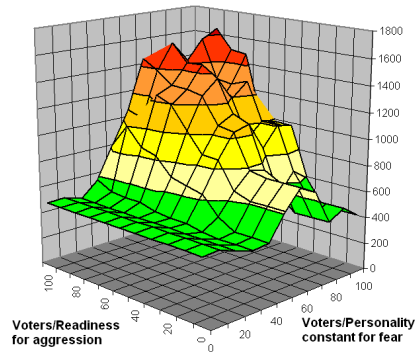


Figure 9: Smoothing of the fitness landscapes in the stochastic model<sup>10</sup> (right) as compared to the deterministic model (left) in case a (upper part) and case b (lower part)

Since this document can only provide examples of the overall process, any further workshop findings are omitted.

#### 4.4.4 Validating the New Movement Planning and the Jostling Mechanism

Several simulation runs were performed with and without jostling leading to the conclusion that the ability of jostling leads to a more plausible course of the simulation. Reality is approximated more closely, not least by the frustration effects on civilians caused by being jostled away. The effect of fearful or unmotivated civilians blocking the polling booth, which had frequently been observed so far (cp. Figure 10) occurred a lot less frequently since these agents in most cases could be jostled away by others.

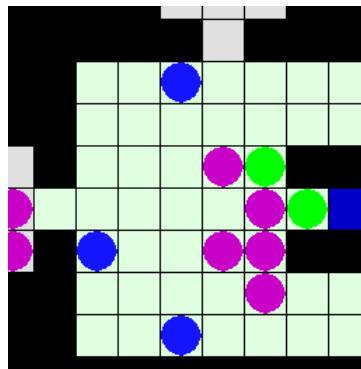


Figure 10: Fearful civilian blocking the polling booth in the model without jostling

Other advantages and enhancements of the jostling mechanism were identified.

<sup>10</sup> showing average values of the 30 replicates in the stochastic case

## 4.5 Conclusion

The group felt that all of its objectives stated beforehand (cp. section 4.2) were achieved and useful ideas for model enhancements and future work within Project Albert had been collected.

A relatively high validity of the model was attested by the group so that future experiments should have their focus on actually examining different action alternatives of the soldiers. The model's validity can be partly drawn upon the following facts:

- The stochastic elements enhance the model in that they smooth fitness landscapes and make the model behavior more realistic.
- The course of the simulation made sense to the group's military experts in most cases – surprises in the fitness landscapes were explainable by looking at the course of the simulation.
- Many findings from real world missions can be found in the model.

Some possible model enhancements and impulses for future experiments are outlined in the following.

### 4.5.1 Possibilities for Further Development

The following very briefly states some of the possible enhancements that the group identified as sensible<sup>11</sup>:

1. Add new possibilities for the soldiers
2. Add new and review existing MoEs
3. Make agents blocking an entrance check their action-leading motive so that a new action can be taken instead of blocking the entrance (e.g. attack the guard - cp. Figure 11)

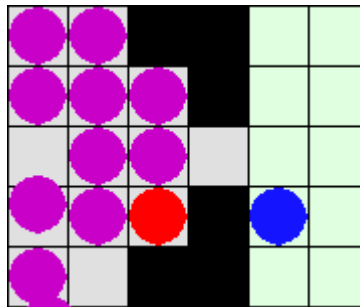


Figure 11: Example for a blocked entrance

### 4.5.2 Suggestions for Future Experiments

Future experiments should focus stronger on the parameters  $N_{controllable}$  that are really controllable during a mission (in the sense of Tactics, Techniques and Procedures) instead of further validating the model:

<sup>11</sup> Unmentioned are bug fixes and minor enhancements. The list is kept very short here since this case study is only of exemplary nature and this section is only to show that the group did indeed identify possible enhancements.



$$N_{input} \xrightarrow{\text{regression}} N_{important} \xrightarrow{\text{definition}} N_{controllable}$$

These factors might include:

- Rule sets of the different troops (maybe including the rule sets' thresholds)
- Number and position of the troops
- Number and position of the barriers set up

The group also pointed out that missions involving crowd control are inherently multi-objective (cp. section 4.2). This should be kept in mind in future experiments.