
Data Farming in Support of Military Decision Makers

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ABSTRACT

Data farming combines the rapid prototyping capability of certain simulation models with the exploratory power of high performance computing to rapidly generate insight into questions. The aim is to develop a better understanding of landscapes of possibilities as well as outliers that may be discovered through simulation experiments. In this paper we will provide an overview of the overall data farming process as well as discuss methods and techniques that are used within the process. These methods include the application of design of experiments to computational experiments in an iterative process of team-based rapid model prototyping, optimized statistical sampling of the experimental design space, high performance computing, multi-dimensional analysis and visualization, and tools and interfaces for executing these actions.

After the concept of data farming was put forth in 1997, the United States Marine Corps utilized the techniques in their Project Albert. This project focused on questions that were fundamental to decision makers, but could not be answered through traditional methods. It relied on the combination of small simulation models, high performance computing, and data farming. During the project, which existed from 1998 to 2006, an international community of interest developed around the topic of data farming. Multi-disciplinary teams of researchers, military officers, and subject matter experts have been using the techniques in collaborative environments since the first international workshop in 1999 and have continued since the project ended.

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DATA FARMING IN SUPPORT OF MILITARY DECISION MAKERS

A great deal of sharing and knowledge transfer takes place at these International Data Farming Workshops (IDFWs). In the past year, IDFW 17 was held in Garmisch-Partenkirchen, Germany and IDFW 18 was held in Monterey, California, USA. At the Naval Postgraduate School in Monterey, much continued work takes place at the SEED (Simulation Experiments and Efficient Designs) Center for Data Farming. And much work has taken place in other NATO and PfP countries. In our paper, we describe these and other continuing data farming efforts around the world, including the exploratory work on data farming support to NATO by NMSG ET-029.

We also describe various efforts to develop simulation models and apply them within data farming environments in support of military decision makers. One such model is the agent-based model PAX, developed by EADS Germany on behalf of the German Bundeswehr. PAX has successfully been applied during the international workshops since 2002. In that context, PAX has been used in concert with data farming, allowing the possibility of performing thousands, even millions of simulation runs on high performance computers. PAX focuses on analyses dealing with Peace Support Operations (PSO) and, recently, operations in support of Humanitarian Assistance.

1.0 DATA FARMING

Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world.
—Albert Einstein

Data farming combines the rapid prototyping capability of certain simulation models with the exploratory power of high performance computing to rapidly generate insight into questions. The aim is to develop a better understanding of landscapes of possibilities as well as outliers that may be discovered through simulation experiments. Data farming focuses on a more complete landscape of possible system responses, rather than attempting to pinpoint an answer. This “big picture” solution landscape is an invaluable aid to the decision maker in light of the complex nature of scenarios that NATO forces are faced with in today’s uncertain world. Data farming allows the decision maker to more fully understand the landscape of possibilities and thereby make more informed decisions. Data farming also allows for the discovery of outliers that may lead to insightful findings.

In the past, data farming has been used to seek insight into questions such as:

- What is the role of trust, or other so-called ‘intangibles’, on the battlefield?
- What impact will net-centric warfare and complete information sharing have on the effectiveness of military units?
- How can we best protect our homeland from a martyr-based offense?
- How can a bio-terrorist attack be mitigated in a free society?
- What system characteristics are important in military convoy protection systems?
- What factors are most important in defeating improvised explosive devices?

Of course, there are many other questions which are of interest, and these are but a few of the ones that teams have attempted to address using data farming.

Data farming is an iterative team process (Horne and Meyer 2004). Figure 1 presents the data farming process as a set of imbedded loops. This process normally requires input and participation by subject matter experts, modellers, analysts, and decision-makers.

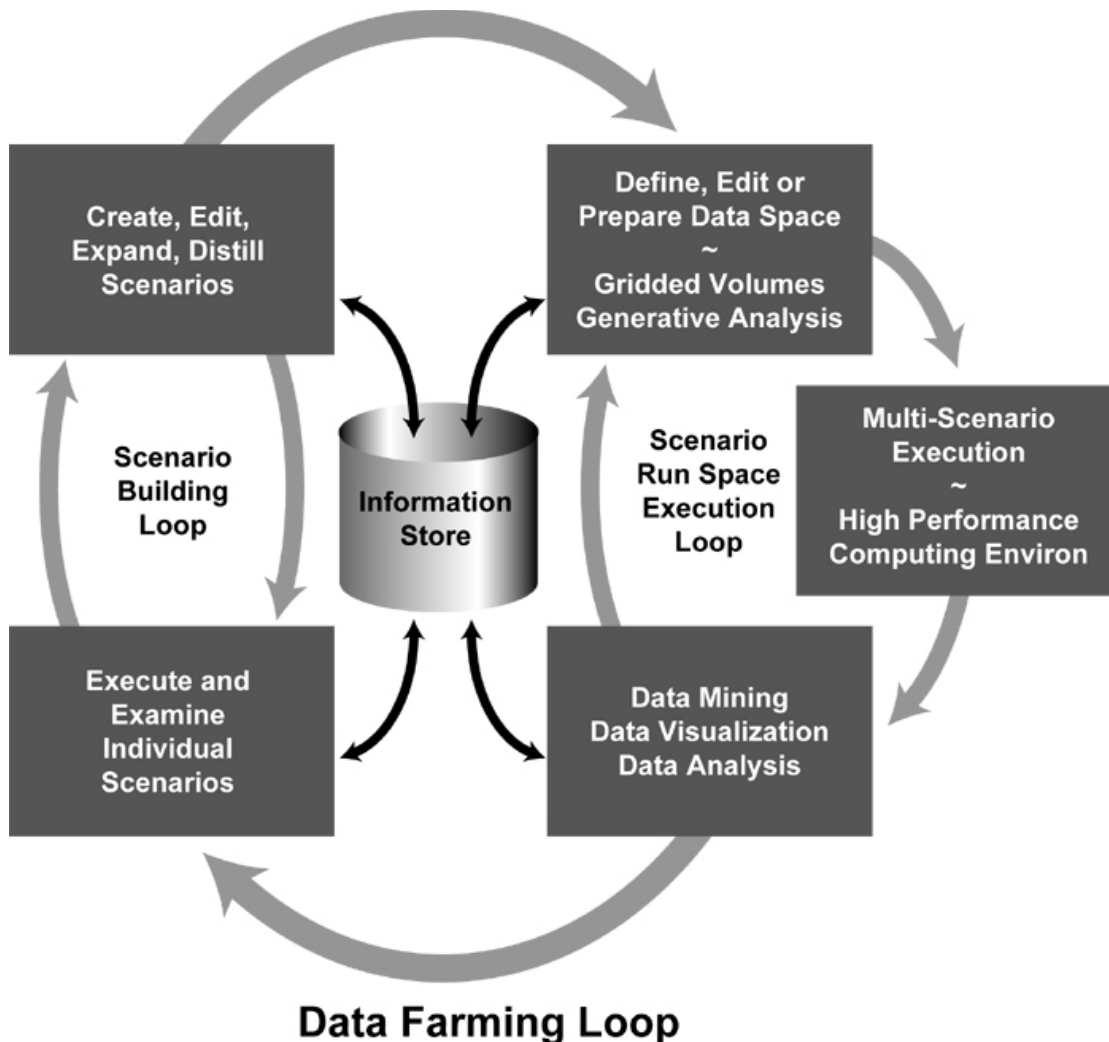


Figure 1: Iterative Data Farming Process

After the concept of data farming was put forth in 1997 (Horne, 1997), the United States Marine Corps utilized the techniques in their Project Albert. This project focused on questions that were fundamental to decision makers, but could not be answered through traditional methods. It relied on the combination of small simulation models, high performance computing, and data farming. During the project, which existed from 1998 to 2006, an international community of interest developed around the topic of data farming. Multi-disciplinary teams of researchers, military officers, and subject matter experts have been using the techniques in collaborative environments since the first international workshop in 1999 and have continued since the project ended.

A great deal of sharing and knowledge transfer takes place at these International Data Farming Workshops (IDFWs). Results have been documented in the proceeding from workshops 13 through 18 (Horne and Meyer, 2006, 2007a, 2007b, 2008a, 2008b, 2009) In the past year, IDFW 17 was held in Garmisch-Partenkirchen, Germany and IDFW 18 was held in Monterey, California, USA. At the Naval Postgraduate School in Monterey, much continued work takes place at the SEED (Simulation Experiments and Efficient Designs) Center for Data Farming. And much work has taken place in other NATO and PfP countries.

NMSG ET-029 has been chartered to explore the possibilities in developing a task group to assess the data farming capabilities that NATO, PfP, and Contact Countries, schools, and agencies have that could contribute to the development of improved decision support to NATO forces. Proof-of-concept explorations involving questions and models of interest to NATO nations also will be undertaken if the task group is approved. This group would then take the results of both the assessment and explorations to recommend and demonstrate a way forward for implementing data farming methods and processes in NATO modelling and simulation contexts. Harnessing the power of data farming to apply it to our questions is essential to providing support to NATO decision-makers not currently available. This support is critically needed in answering questions inherent in the scenarios we expect to confront in the future. Concurrently there is a crucial need to assess the capabilities of NATO, PfP, and Contact Countries, schools, and agencies that could contribute to the development of the science underlying data farming.

The simulations available to NATO analysts are often large and complex. And even the smaller more abstract agent-based models can have many parameters that are potentially significant and that could take on many values. In addition, response surfaces can be highly non-linear. Thus efficient experimental designs and other methods have been employed in the data farming process to begin to get at many of the questions that were previously intractable. We will describe some of our efforts in this area in the next section.

2.0 DESIGNING SIMULATION EXPERIMENTS

Political, social and economic programs are usually more valuable than conventional military operations in addressing the root causes of conflict and undermining an insurgency.

—FM 3-24 Counterinsurgency

The U.S. military uses models for course of action analysis, training and rehearsal, and evaluation for acquisition (Committee on Organization Modeling, 2008). These models may lack utility—and are potentially harmful—if they do not adequately reflect contemporary operations. Yet as conflicts around the world shift from conventional warfare toward irregular warfare, civilian populations are often the determinants of success. Consequently, interest has progressively grown in the development of models that can simulate social behavior as it pertains to military operations. To date there has not been a validated model designed for irregular warfare that covers the instruments of national power: Diplomatic, Information, Military, Economic (DIME) or the Political, Military, Economic, Social, Infrastructure, and Information (PMESII) indicators on which progress in irregular warfare is based (Marlin, 2009). According to the U.S. Defense Modeling and Simulation Analysis Committee, the data to instantiate such a model is either nonexistent or woefully inaccurate, and the validation process of such a model would have to be completely rethought (Committee on Modeling and Simulation for Defense Transformation, 2006).

Yet despite the dearth of data and lack of validated models, it is our belief that many in the defense simulation community can dramatically improve their analyses by using design of experiments (DOE) developed specifically for exploring complex computer models. This, in turn, can provide valuable input to decision-makers. As mentioned earlier, data farming refers to using high performance computation to grow data. The harvested data can then be analyzed using data mining or other statistical techniques. Experimental design is key to successful data farming because it specifies *how* to grow the data. What you reap from the data you grow depends on how effectively you design your experiments.

2.1 Potential Goals

All models are wrong, but some are useful
—George Box (1979)

We believe that the following goals are appropriate for studies of complex simulations—such as those involving models of irregular warfare, peace support operations, and defense against terror.

(i) **Developing a basic understanding** of a particular model or system. That is, seeking insights into the high-dimensional space by identifying dominant factors, significant interactions, and finding regions, ranges, and thresholds where interesting things happen. In the context of simulating irregular warfare and defense against terror, we are typically interested in gaining insights about potential futures, and data may not exist.

(ii) **Finding robust** decisions, tactics, or strategies. In other words, identifying settings for decisions, tactics, or strategies that tend to lead to good outcomes—despite the presence of uncontrollable uncertainties. Since many aspects of social dynamics and irregular warfare are uncertain (and may even be difficult to measure), robustness is particularly important in these domains of M&S.

(iii) **Comparing** the merits of various decisions or policies. Simulation experiments can provide valuable insights to decision makers by demonstrating that one simulated alternative is better than another, or by separating alternatives into those that appear promising and those that can be eliminated from further consideration.

We remark that this requires a change of mindset for those used to viewing simulation experiments as a means of obtaining accurate predictions at untried inputs, optimizing a function of the simulation inputs, or calibrating the simulation results to match physical data; these three goals were espoused by Sacks et al. (1989) in their classic paper on computer experiments, but we argue that they are often not appropriate for simulations of conflict or other complex phenomena. For example, we use the term *insights* rather than *predictions* because it is almost always impossible (due to a dearth of data) for us to provide any warranty on the accuracy of the predictions for potential future occurrences (Hodges, 1991). We seek robust solutions rather than optimal solutions in part because the sheer number, uncertainty, and complexity of uncontrollable factors usually makes optimization infeasible without fixing many uncertain variables. Similarly, calibration is often dubious because there is a shortage of reliable data for many of the situations that we wish to simulate. In some situations, such as disaster relief efforts or large-scale terrorist attacks, we are thankful that these events are not every-day occurrences, and hope that data continue to be scarce. An expanded discussion on this new view on the goals of many analyses using complex simulations can be found in Kleijnen et al. (2005).

2.2 Choice of Design

[We seek designs that] allow one to fit a variety of models and provide information about all portions of the experimental region—Santner et al. (2003)

The selection of an experimental design for simulation experiments depends, of course, on many things. Among the primary considerations are the number of samples that can be taken, the number and levels of factors we desire to vary, any *a priori* assumptions on the response, and the types of models (e.g., regression or graphical models) that we would like to be able to fit using the response data. Fortunately, a rich number

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of designs have been developed that are appropriate for different experimental settings.

Physical experiments are typically applied in settings when there are not too many factors being explored and the response surfaces are fairly simple; e.g., the response in the region of interest is a reasonably smooth (e.g., a linear or quadratic) function of the input factors. Despite their ubiquity, these may not be the most appropriate designs for simulation experiments because of the complexity of the model; they also fail to take into consideration the additional degree of control that a simulation analyst has over someone conducting live experiments. More recently, designs have been (and continue to be) developed for situations in which there are many variables requiring investigation, and the relationships between the inputs and the outputs are more complex. These are the designs that our experience suggests are most appropriate for extracting information in irregular warfare and counter-terror studies. In these situations there are usually multiple responses of interest and little *a priori* knowledge about the forms the response function may take. It thus seems prudent to adopt Santner et al.'s (2003) principle of selecting designs that “allow one to fit a variety of models and provide information about all portions of the experimental region.” While it is almost always impractical to perform physical experiments on more than a handful of factors in physical experiments, it is feasible—with the right software and hardware—to vary scores or hundreds, or even more, factors in computational experiments. Indeed, facilitating this is what the SEED Center for Data Farming is all about.

An in-depth discussion of the types of designs is beyond the scope of this paper. Instead, we refer the reader to Sanchez and Wan (2009) for details about a variety of designs, as well as a flowchart and table to assist analysts in choosing a design. However, of the multitude of designs we have used, in scores of simulations studies, the closest to an all-purpose class of designs when the factors of interest are mostly continuous and there is considerable *a priori* uncertainty about the response are based on Latin hypercube (LH) sampling. When constructing LH design matrices, the input variables are treated as random variables with known distributions. For each input variable x_i , “all portions of its distribution [are] represented by input values” by dividing its range into “ n strata of equal marginal probability $1/n$, and [sampling] once from each stratum,” (McKay et al., 1979). For ease of generation and to provide good space-filling, we usually sample from a discrete uniform distribution. That is, for each x_i , the n equally-spaced input values are assigned at random to the n cases. This generates column x_i in the design matrix, and is done independently for each of the k input variables.

We have found LHs to be good all-purpose designs for several reasons: (i) *design flexibility*: We can readily generate an LH for most any combination of continuous factors and sampling budget. Indeed, if n is large, simple rounding enables us to generate reasonable designs for just about any combination of number of factors and number of levels; (ii) *space-filling*: LHs sample throughout the experimental region—not just at corner points. Specifically, if we look at any group of factors we will find a variety of combinations of levels; and (iii) *analysis flexibility*: The resultant output data allow us to fit many different models to multiple MOEs. In particular, these designs permit us to simultaneously screen many factors for significance and fit very complex meta-models to a handful of dominant variables. This flexibility also extends to visual investigations of the data as we get many cameras on the relationships between inputs and outputs.

Randomly generated LHs have been used for many studies over the years. For any given combination of sampling budget (n) and factors (k), there are $(n!)^{(k-1)}$ possible LH designs generated from discrete uniforms, as specified above. Rather than select one of these at random, we prefer to use a design matrix whose columns are orthogonal (or nearly orthogonal) and that has good space-filling properties; see Cioppa and Lucas (2007). A spreadsheet containing several variations of these “good” LHs for designs involving up to 29 factors can be downloaded from the SEED Center’s website (<http://harvest.nps.edu>). This spreadsheet is regularly updated as new designs become available.

There are many situations where designs other than LHs are more appropriate. This is especially true if we have goals such as factor screening or are willing to make certain assumptions (e.g., the response is linear in the region of interest) about the relationships between inputs and outputs. Our goal is to provide simulation experimenters with a portfolio of readily available designs for use in high-dimensional explorations. For example, fractional factorial and central composite designs have been cornerstones in industrial and laboratory experimentation for decades (Montgomery, 2005). These designs allow experimenters to estimate main effects (linear and perhaps quadratic) and lower order (e.g., two-way) interactions. In most cases, however, these experiments involve a relatively modest set of factors. Consequently, almost all readily available resolution V designs are for experimental situations involving less than about a dozen or so factors; see, for example, NIST/SEMATECH (2009).

To enable analysts to easily generate large resolution V fractional factorial and central composite designs, an algorithm utilizing a fast Walsh transformation (Sanchez and Sanchez, 2005) is available on the Center's website. This algorithm has been used to generate designs as big as $2^{443-423}$, and catalog them with a simple list of Walsh indices rather than extensive tables of confounding patterns. While 2^{20} (roughly a million) runs is a lot, we have taken even larger samples in some of our simulation studies (Vinyard and Lucas, 2002). Furthermore, 2^{20} is a lot less than 2^{443} .

Other approaches that can be useful for computational experiments include sequential screening methods. Many simulations contain a large number of input factors, of which only a small proportion have noteworthy effects. In such cases, one is often interested in identifying those significant factors—perhaps so that additional experimental efforts can focus on them. Recently, several sequential methods for simulation screening have been proposed. First, Bettonvil and Kleijnen (1997) proposed a method called sequential bifurcation (SB) that iteratively screens groups of factors until each input factor is classified as either significant or not. They show that this approach is very efficient when the directions of effects are known and there are only a small proportion of critical effects. Wan et al. (2006, 2009) improve on SB, with a method they call controlled sequential bifurcation (CSB), by allowing the user to specify limits on both type I errors and power for all effects. Building off of Wan's et al.'s CSB designs, hybrid two-phase approach that combines efficient fractional factorial experiments with CSB. These new designs have proven robust to some of the strong assumptions required in SB methods (such as being able to specify the direction of effects) and they are surprisingly effective and efficient; see Sanchez et al. (2009), Shen et al. (2009).

2.3 Benefits of Designed Experiments

What may not be obvious at first glance is how quickly it becomes computationally infeasible to conduct full factorial designs on individual factors—even for a relatively simple simulation model. For example, suppose that the simulation has twenty factors that can be varied, the scenario has ten factors, and there are four manipulations. A full factorial design involving only low and high levels (i.e., no intermediate levels) for each factor for this single organization has $2^{20} \times 2^{10} \times 4$ runs per replication. Even if the computational model runs in one second, this requires 136 years of computer processing time! And, unless the response variances can reasonably be assumed to be constant, two or more replications are needed in order to estimate the effects with any statistical validity. Given that there are hundreds or thousands of factors in many models of military operations, it is easy to see why practitioners unaware of the power of experimental design have limited their studies to a small number of factors or groups of factors. However, this also severely limits the types of insights that can be gleaned from a single simulation study.

3.0 SEED CENTER FOR DATA FARMING

Once you have invested the effort to build (and perhaps verify, validate and accredit) a simulation model, it's time to let the model work for you! –Lucas and Sanchez, 2009

Complex simulations will continue to be an increasingly important tool for those charged with informing decision makers in defense, including irregular warfare and counter-terror operations. It is our belief that much more information can be extracted from these simulations by combining relatively inexpensive, high-performance computing; a new mindset on the information gleaned from many simulations; and DOE tools for high-dimensional simulation exploration. Of course, the vast majority of simulation practitioners are not experts in designing simulation experiments. Thus, we must make doing so easy for them. For this purpose we have created the SEED Center for Data Farming, and are working to strengthen ties in the international defense modeling and simulation communities.

The Center provides many resources online at <http://harvest.nps.edu>, including links to student theses that use a variety of designs on a diverse set of models and studies. Indeed, SEED Center techniques have been used to investigate issues relating to the following areas: Fighting the global war on terrorism, convoy operations, peacekeeping, non-lethal weapons, urban combat, unmanned (air, ground, sea, and subsurface) vehicles, logistics in support of urban humanitarian assistance, future networked enabled forces (such as the Future Combat System FCS, Marine Distributed Operations (DO), and the Future Force warrior (FCS))—and many more. These applications are a good source for finding information on the output analysis techniques we have found useful for exploring, large sample, high-dimensional, simulation output data.

Spreadsheets and software for generating the designs are also available from the SEED Center's web pages, along with publications that provide details about the methodological advances and a variety of applications. Finally, the SEED web pages have links to other resources, including information about the bi-annual International Data Farming Workshops. The next IDFW is scheduled for November 2009 in Auckland, New Zealand.

4.0 SIMULATION MODELS – TWO EXAMPLES

This section describes two efforts to develop simulation models with different scopes and strengths exemplarily. The first agent-based model named PAX (Latin word for “peace”) was developed by EADS Germany with the goal to model human factors and has successfully been used during the International Data Farming Workshops since 2002. The second model named ABSEM (agent-based sensor-effector model), is also being developed by EADS Germany and focuses on a physics based model of sensors and shooters. This tool has been used during the IDFW since spring 2008. Both models allow the possibility of performing thousands, even millions of simulation runs on high performance computers in data farming analyses. They have been developed on behalf of the German Bundeswehr. It is planned to merge the two models due to their basic compatibility on model and representation level to get a data farmable model with strengths in the areas of human behaviour representation as well as a complex physics model and combinations thereof.

4.1 The agent-based model PAX

PAX models human factors with the focus on the behavior and interaction of both military personnel and civilians. The modeling approach includes the process of human decision-making, the psychological aspects regarding the evolving aggressiveness of non-military entities, and a detailed representation of individuals and groups consisting of civilians as well as soldiers. The dynamics of emotional states such as fear and anger and their impact on the behavior of actors as well as stress are also modeled. PAX allows analyses of Peace Support Operations (PSO), operations in support of Humanitarian Assistance and enables investigations in the context of irregular warfare (IW).

PAX agents basically represent individuals. The civilian agent model contains 3 basic processes which determine the individual level of aggression. Needs and emotions influence the level of aggression and a process of de-individuation determine the contribution of personal norms of anti-aggression. "Need", "anger", "fear" and the "readiness for aggression" are modeled as state variables. The value of these variables will change dynamically, depending on events in the agents' environment (e.g. actions of other agents). De-individuation describes a state of the agent in which he considers himself as part of a crowd and not as an individual. It is the basic concept that allows to model groups of agents and group cohesiveness.

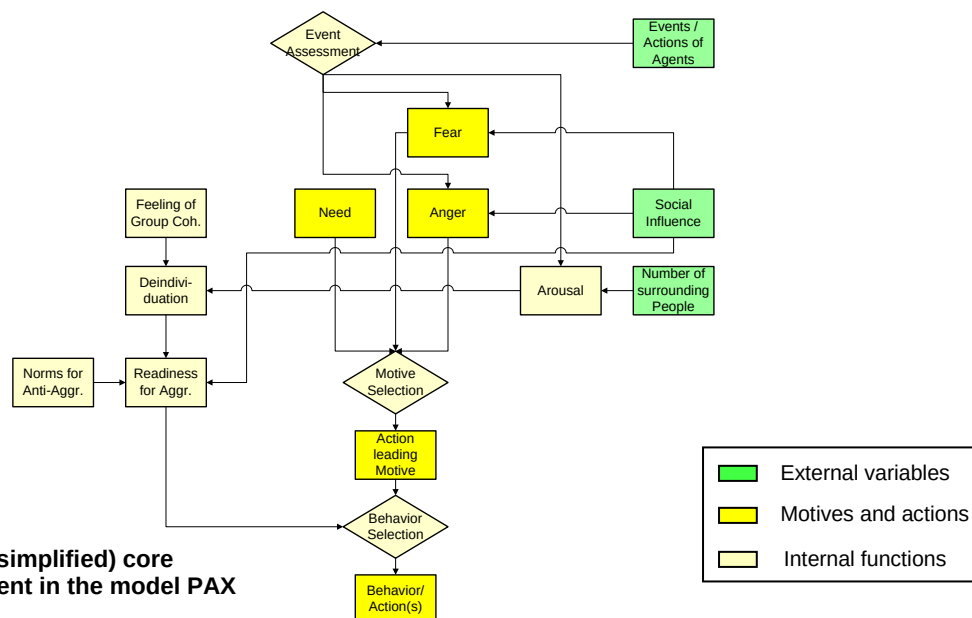


Figure 2: The (simplified) core of a civilian agent in the model PAX

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Figure 2 depicts the civilian agent model. The civilian agent's behavior mainly depends on his motivation. Besides fear and anger, there is (among others) a basic motive to satisfy a certain need, e.g. to get a food package. Motives are correlated each to a specific goal and compete against each other. The motive with the highest intensity at a particular point of time is selected as action-leading motive and predetermines the main direction of the behavior.

The soldier agents in PAX can be assigned different tasks, such as guarding the entrance to a camp or supporting the distribution of food packages, for example. In case of aggressive actions of certain civilians, the soldiers may react with pacifying, threatening or defensive actions towards these civilians. The soldiers' RoE can be implemented by respective rule sets that describe the agents' goals and personalities. The following is a simple example for a mainly de-escalating rule set description: If civilians act aggressively, soldiers try to calm down the situation by always trying to pacify the civilians, no matter what the situation is like. Threatening or defensive actions are never chosen.

PAX agents interact with each other. A soldier agent's actions such as pacifying, threatening or defending are, in a first step, assessed by the other agent (event assessment). Depending on the type of event and the agent's personality, the cognitive assessment may evoke fear, anger and arousal, and possibly cause stress.

Understanding the complex dynamics of human behavior and interaction is extremely important for PSO. The type of challenges coming along with this kind of operations might best be described by an Example: Recent war activity and relocation of civilians to refugee camps have given way to a new set of challenges for military forces. The challenges faced by military personnel stationed in a refugee zone are quite different from those in a classic conflict situation such as a war zone. For example, military forces stationed in a refugee camp are usually not confronted with a heavily armed enemy, but with hungry, scared, or in some cases enraged civilians. The involvement of military forces requires the understanding of the given situation and contextual behaviors of the people involved in the situation. In the case of the refugee scenario, it is necessary to understand how civilians will react within the camps. Important questions to understand include: Will the civilians in the refugee camp remain peaceful or will they become aggressive? Should the soldiers keep a low profile or take strong actions to maintain peace in the camp? What level of involvement is necessary to de-escalate a situation created by an enraged civilian? Are the current rules of engagement adequate or should they be modified to better address issues that may arise in a refugee camp? The answers to these questions are required for the operational and tactical aspects of military involvement in such a refugee scenario.

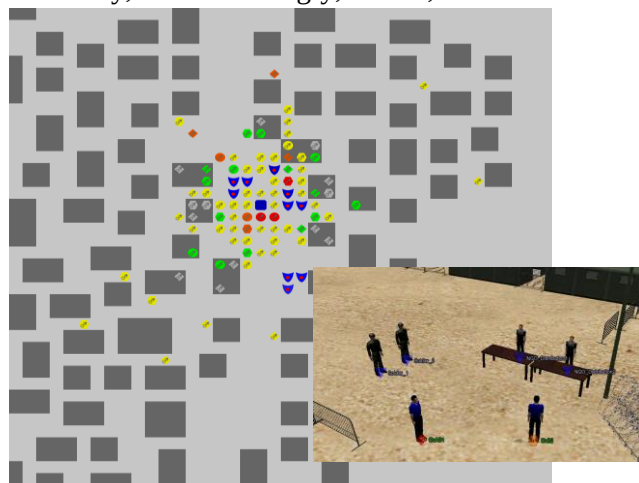


Figure 3: Refugee Camp in PAX 3.0 and PAX 3D

PAX studies attempt to analyze these kind of questions using the described human factors and behaviour modeling. The main application of PAX is to study and potentially modify current Rules of Engagements (ROE) for specific scenarios in the context of PSO. Another matter subject to investigations with PAX is to better understand situations of interest and how they could evolve with the goal of identifying indicators by which potential escalations might be recognized in an early state. Examples for examined scenarios are operating refugee camps, securing elections or crowd and riot control.

4.2 Agent based sensor effector model (ABSEM)

Analyzing the advantages of networked sensors and effectors for military capabilities in network centric operations (NCO) becomes more and more important in times of asymmetric warfare. Former studies showed, however, that existing agent based models are rather limited in terms of modeling and simulating complex technical systems on a sound physical basis. For this reason a new agent based model that aims to fulfill the requirements to be used for analyzing the combination of various sensor and effector systems in NCO and taking into account underlying physical theories was developed. Therefore objectives for modeling complex technical systems were defined: examining the performance and value of existing sensors and effectors - those under development and future ones during military operations -, analyzing the combination of various sensor and effector systems in NCO, support simulation of different levels of abstraction and the possibility to use the model within the data farming process (as distillation model) as well as within distributed simulation networks (higher level of detail).

A first prototype of ABSEM was presented to the International Data Farming Community at IDFW 17 (Figure 4).



Figure 4: ABSEM logo

ABSEM is an agent based realistic and dynamic simulation with dynamically and individually interacting entities and the possibility to consider non-linearities and intangibles, so that the highly dynamic character of multi-party scenarios can be captured. The driving force behind agents' behavior is list of goals and tasks, e.g. motion tasks (patrol, move to, follow, escape), battle tasks (attack, defend), communication tasks and transportation tasks. The allocation of tasks is initially (when setting up the scenario), dynamically (at runtime, as a reaction to outside influences or as an result from an internal decision processes) and state-oriented (defining what has to be achieved, but not how).

In addition to a distillation model for data farming, that is significantly faster than real time, ABSEM supports a high resolution model for detailed analyses in a federation of networked simulation systems. This implies the necessity to stay close to RPR-FOM where the agents' "public" state (entity type, force identifier, damage state, spatial...) is described. In the high resolution mode ABSEM is able to be part of and to provide computer generated forces for a VIntEL experiment (see publication: Distributed Integrated Testbed in these procedures). In addition ABSEM is used to prepare VIntEL experiments by data farming the relevant parameters and setups as well as post process the high resolution results via data farming.

For modeling sensors in ABSEM a detailed physical approach is used in contrast to the probability based approach which is used in previous agent based simulations. So far normal human viewing, residual light amplifiers (short waved IR), thermal camera (middle and long waved IR - Figure 5) and radar sensors are modeled. The ABSEM sensor input consists of background information, e.g. (temperature, contrast), target information (temperature, signature) as well as atmospheric conditions and weather history. The ABSEM sensor output is a list of perceived entities in the sensor's field of view / field of search, along with the attribute "detected", "classified" or "identified".



Figure 5: Infrared view

For effectors in ABSEM the goal is to determine the point/area of impact as well as the damage done to the target. Two types of weapons are distinguished: weapons with point impact (e.g. pistols, rifles) and weapons with area impact (e.g. grenades, mines). The hit probability and kill probability depends on the weapon system, the environmental parameters and the target characteristics. ABSEM differentiates between the six

damage levels: no effect, mobility kill, firepower kill, mission kill, communication kill and catastrophic kill. ABSEM as a data farming model makes an idealization and stochastic modeling necessary to some extent to simplify very complex processes. Consequences are a parabolic idealization of ballistic trajectory, an impact point which depends on dispersion and no detailed physical attrition modeling.



Figure 6: ABSEM camp protection scenario

During the last three IDFWs a camp protection scenario was used to validate and test the performance of ABSEM (see Figure 6). During these experiments, the sensor performance of different sensors with the measures detection/ classification/ identification times and distances under varying conditions (day and night, different atmospheric conditions and seasons - Figure 7) was analyzed. Additionally the performance of different weapons was examined, varying the marksman dispersion and recording caused damages.



Figure 7: ABSEM weather: fog, day, night

As results the advantages of different sensor types for given scenarios and conditions can be evaluated by the defined measures of effect (MOE) like destroyed vehicles in a patrol convoy (Figure 8). The important factors for the MOE can be evaluated with regression trees as shown in Figure 9.

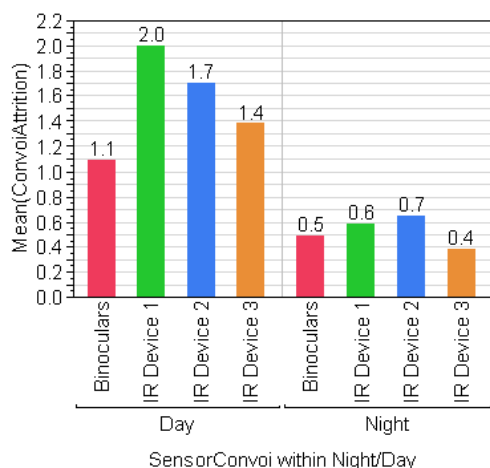


Figure 8: MOE over different sensor types

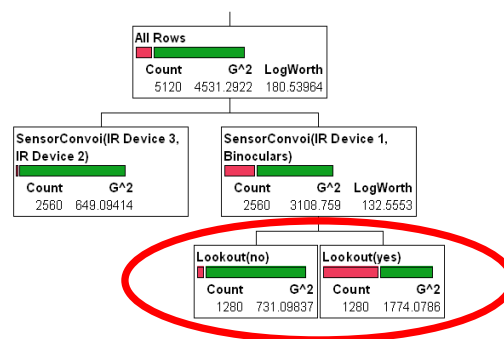


Figure 9: Regression tree

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