Warfare Simulation and Technology Forecasting in Support of Military Decision Making

Eric Malmi, Ville Pettersson, Sampo Syrjänen, Niina Nissinen,
Bernt Åkesson, Esa Lappi
Defence Forces Technical Research Centre
Electronics and Information Technology Division
P.O. Box 10, FI-11311 Riihimäki, Finland
e-mail: eric.malmi@gmail.com, ville.h.pettersson@gmail.com, shsyrjan@gmail.com, niina.nissinen@mil.fi,
bernt.akesson@mil.fi, esa.lappi@mil.fi

***Abstract*—We describe a methodology that uses warfare simulation, data farming and technology forecasting in support of military decision making. Our approach explores the vast space of parameters regarding unknown properties of future weapon systems and other uncertainties that affect the outcome of a battle. Characteristics of successful outcomes are identified, providing insights to such questions as what kind of investments should be made to meet future challenges.**

Keywords-warfare simulation; data farming; stochastic simulation; decision support system.

I. Introduction

Technology forecasting serves two purposes in the military context: planning investments of future weapon systems and anticipation of an adversary's future capabilities. In the former, different weapon systems that will be available in the future are modelled and their contribution to one's own performance is analyzed. This analysis supports the decision making regarding what kind of investments should be made to optimize our future performance. In the latter, the adversary's possible future weapon systems are modelled and analyzed. This gives suggestions about preventative actions for meeting the future challenges.

To simulate the course of a battle on operational level, autonomous simulation software is usually insufficient. Instead, one needs to employ wargaming in which tactical decisions are made by a human operator and weapon system effects are simulated by the software, so called man-in-the-loop simulation. In this paper we focus on one such software which enables wargaming: combat modelling tool Sandis [1], which is developed at the Finnish Defence Forces Technical Research Centre. Sandis is based on probability calculus and fault logic analysis and can be used for comparative scenario-based analysis from platoon to brigade level. In Sandis, the player deploys the troops on a map and gives them movement and firing commands. As output, Sandis gives probability distributions of the unit strengths, operation success probability as well as a killer-victim scoreboard and medical situation average values.

The outcome of a wargame is influenced not only by the tactical choices made during the battle but also by the various simulation parameters. There may be variation in the parameters due to uncertainties in future technology or uncertainty in the decisions the adversary makes. In addition, we may want to study the effect of different actions and conditions or test how, e.g., the choice of ammunition type affects the results. These variations create a vast space of parameter combinations that needs to be thoroughly studied. It is often, however, impossible to calculate or play all the combinations. The concept of data farming [2], [3] addresses this problem.

The use of warfare simulation for evaluation of future weapon systems has been discussed in [4], which also included an evaluation of the applicability of Finnish simulation tools to such problems. Data farming has previously been applied to the Sandis combat model in [5], [6].

The methodology presented here bears some similarity to the approach presented in [7]. The approach presented in that paper was intended to support the planning of military operations, and consisted of constructing and evaluating possible futures, however, without applying data farming. The approach utilized various forms of warfare simulation as part of the evaluation process.

In Section II, we discuss the wargaming procedure. After this, in Section III, we present how the outcomes of battle variations are commonly analyzed and what kind of visualizations are used to support the analysis. Finally, in Section IV, we discuss the pros and cons of the methodology we have presented and future work.

II. Wargaming Procedure

In our method the battle is simulated in three phases. The first phase is the initial data farming phase, which consists of automatically computing several possible initial states of the battle from the initial state of the scenario. The second phase is the selection of representative cases, in which a small number of representative cases – say three – is chosen from the automatically generated initial states. In the third

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phase these representative cases are played manually with one or more human operators making the tactical decisions. If we wish to study long battles, these three phases are repeated. The data farming phase begins whenever we need to study the effect of some uncertain parameters. The process in whole is illustrated in Figure 1.

A. Data Farming Phase

The data farming phase consists of choosing the different parameters we wish to vary, e.g., the accuracy of some weapon system, and then automatically simulating their effect. The vast number of possible parameter combinations can be explored efficiently with so called data farming methods [2], [3].

Data farming is the process of running a simulation several times over a large parameter space, and analyzing the simulation results for statistical trends and outliers. It is often impossible to model or predict complex real world phenomena accurately due to several uncertainties. Data farming addresses this problem by not trying to come up with a single definitive answer or prediction, but instead computing the entire landscape of possibilities in hope of understanding and gaining insight on the phenomenon.

Important elements in the data farming process are design of experiments, high performance computing, and analysis of results. The experimental design step includes choosing the appropriate computer models and the key parameters we are interested in. In the high performance computing step we run the simulation over several possible parameter combinations in a high performance computing environment. The analysis of results is often done by using standard statistical methods and visualization on the simulation output.

The data farming framework is not restricted to a particular simulation tool, any simulation software or computational model can be used. Several standard methods have been developed to facilitate the data farming process, such as the latin hypercube sampling [8], [9]. Latin hypercube sampling is a method that assists the parameter space exploration in the experimental design step. Instead of running the simulations for all possible parameter combinations, which is often impossible, latin hypercube sampling chooses a small subset of the parameter combinations with the intention that the subset covers the parameter space well. This reduces the amount of computational resources required without compromising the quality of results too much.

B. Selection-of-Representatives Phase

The data farming phase produces a very large number of simulated variations that can be used as initial states for manual wargaming. Ideally we would like to play each variation manually, but this is often impossible since manual wargaming is time and labour consuming. In the selection phase only a small number of representative cases is chosen for manual wargaming. The number of representative cases should be sufficiently small considering the available resources, but still large enough to cover the important aspects in the simulation results.

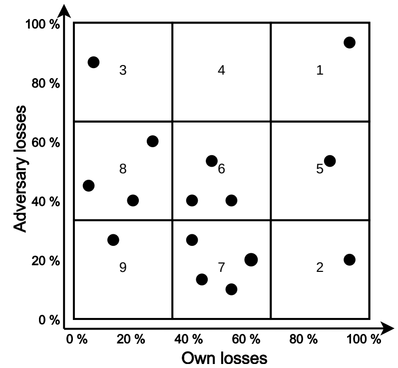

Figure 2. Illustrating the selection of representative cases by means of a scatter plot of adversary lossed versus own losses. Each dot corresponds to a simulation run with a certain combination of parameter values. The plane is divided into nine categories from which a few representative cases are chosen as initial states for the following wargaming phase.

Methods that are used to analyze and visualize data farming results can be useful in this phase. One way to choose the appropriate representative cases is to choose two interesting variables that describe the simulation results, and make a two-dimensional scatter plot of all the simulation results with these two variables as axes. In the military context the numbers of casualties on both sides are often the most interesting variables. The plotted variations can then be divided into nine categories as seen in Figure 2. Representative cases are chosen within those categories. One can eliminate uninteresting cases, such as the cases where both sides have been practically defeated.

As an example, consider Figure 2. Suppose that the x-axis represents own losses and the y-axis represents enemy losses. The cases have been divided into nine categories. Categories 1 to 5 do not need to be manually played, since in those cases at least one side is already defeated. Category 9 only contains one case, which is close to the cases in category 8. The representative cases can be chosen from categories 6, 7 and 8.

C. Gaming Phase

Once the initial parameters have been set, the gaming phase starts. In the gaming phase one or several scenarios are played out. The scenarios are derived from threat models and assumptions on how each side will use its forces and weapon systems [4]. Simulation tools are used to provide estimates of how each scenario will unfold. The scale of the combat analysis determines which simulation tools are suitable. One can distinguish between technical level, combat technical level, tactical and operational level analysis. For tactical and operational level analysis, man-in-the-loop simulations are often necessary. These simulation tools are based on tactical

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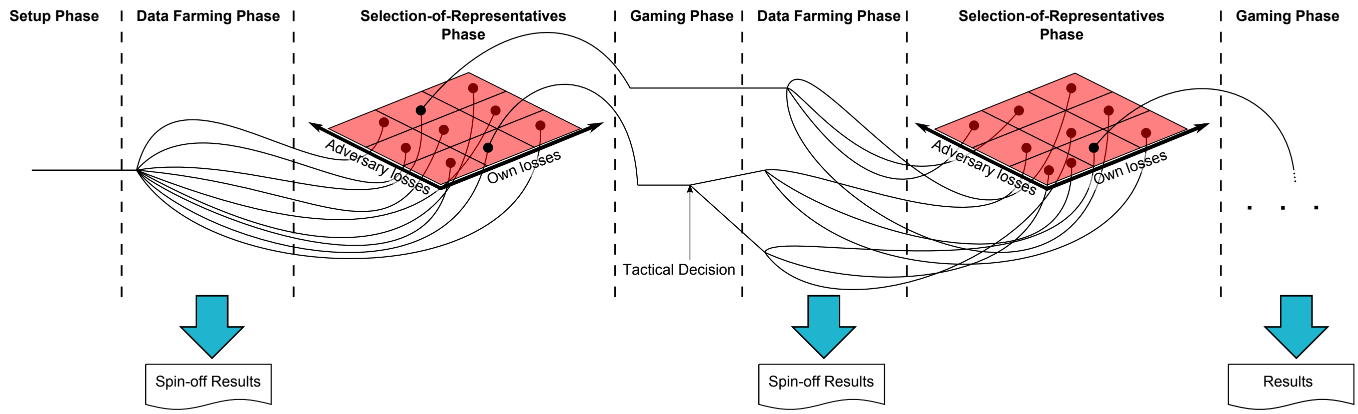

Figure 1. Illustration of the wargaming procedure. The process comprises three phases, which are repeated as necessary.

and technical models, and they calculate the effects and status of battlefield systems, whereas tactical decisions are done by a human operator. The operator decides, e.g., where to move the troops and what kind of firing commands the troops will follow. Once the operator has defined the tactical decisions, the simulation software calculates the outcome of the battle.

We have applied this methodology mainly with combat modelling tool Sandis [1]. A central componenent of the Sandis software is a map interface for wargaming. The units are deployed on the map and given movement and firing commands as input. The strengths of the units are probability distributions and combat losses are modelled as loss probabilities, calculated using a collection of weapon effect models. Additional calculation models include models for radio communication and medical evacuation. A feature of Sandis is that the calculation is based on Markov chains instead of Monte Carlo methods.

Sandis is designed for platoon to brigade level combat simulation. This provides a suitable scale for a wargame. However, we could use high-resolution simulation tools for analysing details and transfer the results of these analyses to the brigade-level wargame, bearing in mind that such a multi-level approach is very labour intensive [4]. Examples of sub-problems, which may require high-resolution simulation, include tank duels, in which individual tanks are simulated, and sensor system evaluation.

Making tactical decisions is the labour consuming part of the gaming phase. If we wish to continue with a new data farming phase, it is possible to automate the varying of the parameters and running of the simulation, once the baseline scenario has been played. Sandis also enables the operator to go back and forth in the timeline after the calculation has been finished. If the operator detects that an unrealistic tactical desicion has been made in the middle of the battle after some parameter change, the command can be refined and the simulation can be recalculated from that moment onwards. Certain parameter values may demand changes in the tactics of either side. The operator may also be forced to manually model the effect of some system or event. This may be the case when the simulation tool lacks the computational model of a particular system.

Furthermore, at some point in the scenario, it may be necessary to branch the scenario and investigate, e.g., two paths. Such a decision point may be whether a defensive position holds or is overrun, which leads to two different end states in the scenario. It is up to the operator to identify such critical points and divide the scenario into a number of major steps. Based on the plans for each side, such critical points could be identified beforehand, as discussed in [7].

In Sandis the manually played wargame scenarios are stored as XML files, as are units and their equipment and parameter data for weapons and equipment. For the data farming phase, the fields corresponding to the parameters to be varied are changed in accordance with the design of experiments, either by directly editing the files with scripts or by creating new versions of the files. The set of scenario files is executed in Sandis and the results from each simulation run are output to plain-text files, which are processed in the analysis step.

III. Analyzing the Results

The wargaming and data farming phases produce a large amount of simulation results that can be analyzed to gain insight on the research question at hand. Some simple analysis methods were already mentioned in the description of the wargaming procedure, but in the final analysis phase the results can be studied more thoroughly and from many angles based on chosen decision criteria. One can use, e.g., cost effectiveness analysis. In this section we describe some useful analysis methods.

As mentioned earlier, one common analysis method is making a two-dimensional scatter plot of all the computed variations. The dimensions of the plot can be any two interesting variables, e.g., casualties on both sides. The dots corresponding to favorable results, i.e., results where

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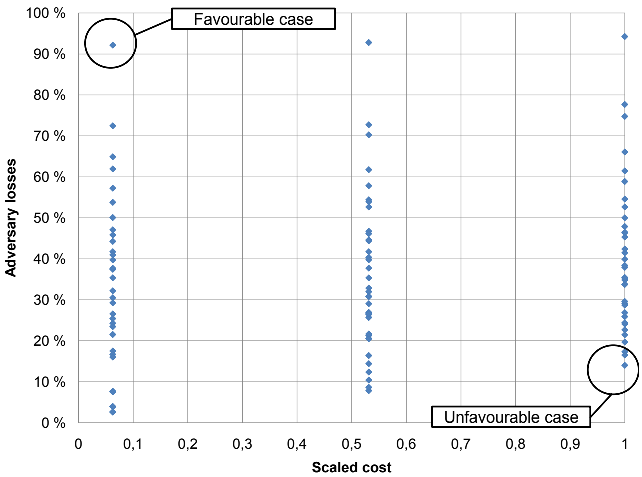

Figure 3. Scatter plot of adversary losses versus scaled own costs in a simulated scenario. Each dot corresponds to a simulation run with a certain combination of parameter values. In the lower right corner are cases where the adversary losses are small and one's own costs are high, i.e., the least cost effective cases. In the upper left corner, on the other hand, are cases where heavy losses are caused to the adversary for small costs.

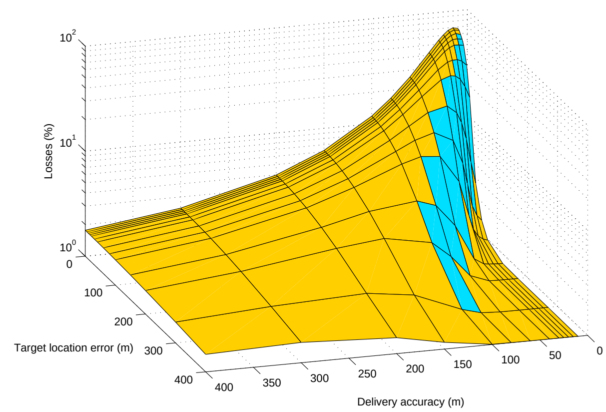

Figure 4. Example of visualization of data farming results. For a specific type of target element, i.e., an infantry soldier in hasty defence, the best indirect fire ammunition can be found. The delivery accuracy for the weapon is in this case expressed by the standard deviation in a circular bivariate normal distribution centered at the aimpoint. The target location error (TLE) is the difference between the true target location and the aimpoint. The colour of the surface indicates the most effective ammunition type for a given combination of delivery accuracy and TLE.

own losses are low and enemy losses are high, are studied in detail to gain insight on what made these cases good. Similarly, the results where own losses are high and enemy losses are low are studied to find out what should be avoided. Strategies and investment plans can then be improved to move towards the favorable results.

As an example of cost effectiveness analysis, consider Figure 3 that has been taken from real-world calculations. The x-axis shows the expected cost for an operation, and the y-axis shows enemy casualties. The values have been scaled to between 0 and 1. Each dot corresponds to one simulation run with some combination of parameters. Results from the simulations have been combined with cost information related to ammunition and equipment. Dots in the upper left corner correspond to favourable scenarios, where large enemy forces can be deterred in a cost effective manner. On the other hand, dots in the lower right corner correspond to unfavorable scenarios, where the enemy takes less losses despite the higher cost.

The parameter combinations and tactics that led to favorable outcomes can then be studied in detail. For example, one might find that some relatively cheap weapon system is effective when used properly while other more expensive systems do not perform well – a useful result when planning investments and strategy. Another possible result is to identify parameters, which have a strong influence on the outcome. The value of some weapon system parameter may have a large effect on the results, while the value of some other parameter may have a surprisingly small effect. These kinds of observations can be used to focus research efforts on improving the more important parameters of future weapon systems.

An example of how results from the data farming phase can be visualized is shown in Figure 4. From a data set of over 19 000 simulation results, generated through variation of several parameters, the most effective indirect fire ammunition against a particular type of target can be found with respect to two parameters: delivery accuracy and target location error. The delivery accuracy for the weapon describes the probability the ammunition hits a particular coordinate point and is expressed by the standard deviation in a circular bivariate normal distribution centered at the aimpoint. The target location error is defined as the difference between the true target location and the aimpoint. It is here treated as a systematic error, which is varied by moving the aimpoint.

It can be noted that the results from the data farming phase, besides providing a foundation for the wargaming, can be valuable as such and can be used to gain insight into the properties of weapons systems. Results like this are referred to as spin-off results in Figure 1.

IV. Conclusion and Future Work

A methodology combining warfare simulation, data farming and technology forecasting for military decision support has been presented. Using data farming the effect of system parameters on the outcome of the battle can be studied.

One downside of our methodology is that the wargaming phase is labour intensive, since it cannot be easily automated. This limits the number of different tactical alternatives that can be tested. The methodology is mainly intended for supporting peacetime aquisitions and planning when there is much time available. As noted in [4], evaluating different modes of operation for the adversary is crucial. Otherwise we might optimize the defence system for the wrong type of threat. Selection of scenarios for the analysis and selection of representative cases for a further gaming phase are therefore of importance.

We will continue to develop the methodology and incorporate additional features in order to handle a broader range of military problems. Although the wargaming process described in this paper utilizes only one simulation tool, the process can be extended to a multi-level multi-resolution simulation process, in which several simulation tools are used. After a specific detail has been analysed in a high-resolution simulation, the results can be transferred to a brigade level analysis tool, such as Sandis. This was discussed in [4]. Furthermore, when evaluating several branches of a scenario, it may be necessary, due to limited simulation resources, to play the most probable or most important branch thoroughly and the less important ones using a cruder simulation model [7]. Finally, although the domain studied here is land warfare, the methodology is applicable to all branches and the defence forces as a whole.

REFERENCES

[1] E. Lappi, "Sandis military operation analysis tool," in *2nd Nordic Military Analysis Symposium*, Stockholm, November 17–18 2008.

[2] G. E. Horne and T. E. Meyer, "Data farming: discovering surprise," in *Proceedings of the 2004 Winter Simulation Conference*, Washington, D.C., December 5–8 2004.

[3] G. E. Horne, "Summary of data farming," in *4th International Sandis Workshop*, ser. Defence Forces Technical Research Centre Publications, J. S. Hämäläinen, Ed. Riihimäki: Defence Forces Technical Research Centre, 2011, vol. 23.

[4] E. Lappi and B. Åkesson, "Combat simulation as a tool for evaluation of future weapon system and some risks in scenario based wargaming," in *Proceedings of the Conference Security in Futures – Security in Change*, ser. FFRC eBook, B. Auffermann and J. Kaskinen, Eds. Turku: Finland Futures Research Centre, University of Turku, 2011, vol. 5/2011.

[5] R. S. Bruun, J. S. Hämäläinen, E. I. Lappi, , and E. J. Lesnowicz Jr, "Data farming with SANDIS software applied to mortar vehicle support for convoys," *Scythe: Proceedings and Bulletin of the International Data Farming Community*, no. 9, 2011.

[6] J. Hämäläinen, P. Rindstål, R. Vuorsalo, R. Bruun, and J. Tiainen, "Using Sandis software combined with data farming to analyze evacuation of casualties from the battlefield," in *4th International Sandis Workshop*, ser. Defence Forces Technical Research Centre Publications, J. S. Hämäläinen, Ed. Riihimäki: Defence Forces Technical Research Centre, 2011, vol. 23.

[7] D. R. Pratt, R. W. Franceschini, R. B. Burch, and R. S. Alexander, "A multi threaded and multi resolution approach to simulated futures evaluation," in *Proceedings of the 2008 Winter Simulation Conference*, Miami, FL, December 7–10 2008.

[8] M. D. McKay, R. J. Beckman, and W. J. Conover, "A comparison of three methods for selecting values of input variables in the analysis of output from a computer code," *Technometrics*, vol. 21, no. 2, pp. 239–245, May 1979.

[9] T. M. Cioppa and T. W. Lucas, "Efficient nearly orthogonal and space-filling latin hypercubes," *Technometrics*, vol. 49, no. 1, pp. 45–55, February 2007.

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