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# Agent Based Modelling and Simulation – applicability within OR at FFI

Ole Jakob Sendstad and Stein Malerud

Norwegian Defence Research Establishment (FFI)

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## Approved by

| | |
|---|---|
| Stein Malerud | Project manager |
| Jan Erik Torp | Director |

# Sammendrag

Innen militære anvendelser av operasjonsanalyse utgjør simuleringsmodeller en viktig del av verktøyene. Modellene er bygget for å øke innsikten i et spesifikt system. Systemet kan for eksempel være tapsberegninger i landoperasjoner eller teknisk tilgjengelighet av fly. Så langt har modellene hovedsakelig vært fokusert på de teknologiske sidene av problemstillingen.

For tiden utgjør lavintensitets operasjoner en stadig større del av de militære operasjonene. I disse operasjonene er menneskelig beslutningsfatning og atferd mye viktigere enn i kald-krig scenariene. Målet med en operasjon nå er ofte å redusere spenningsnivået i en konflikt, mens tidligere var målsettingen fokusert mot tapspåføring. Dette betyr at den relative betydningen mellom teknologi og menneskelig atferd har endret seg mye når det gjelder hva som påvirker suksess i en militær operasjon.

Agentbaserte modeller er en alternativ måte å beskrive militære operasjoner på. Fremdeles er det snakk om simuleringsmodeller, men agentbaserte modeller har typisk mer fokus på menneskelig beslutningsfatning, på bekostning av nøyaktige representasjoner av teknologien. En annen forskjell er nivå på input: Agent baserte modeller beskriver hver agent med input (dvs lavnivå), mens atferd på høyere nivå (gruppas totale atferd) er noe av det som kommer ut av modellen. Tradisjonelle modeller derimot har typisk ”scripted” forløp, som betyr at atferd og valg på det øverste nivået er gitt fra input.

Så langt har ikke FFI anvendt agentbaserte modeller inne operasjons analyse. Like fullt anvender en del tilsvarende organisasjoner slike modeller, og denne rapporten beskriver et utvalg av disse anvendelsene. Trenden her er at de mest lovende anvendelsene er menneske fokusert, dvs at menneskelig beslutningsfatning og atferd er grundig representert.

## English summary

Within the Military Operations Research community, simulation models constitute a crucial part of the analysis tool box. These models are built in order to enhance the understanding of a specific system. The system can for instance be attrition based land warfare or technical availability of aircrafts. So far these models have been concerned mainly on the technological part of the problems.

Nowadays, low intensity operations constitute an increasing amount of the relevant military operations. Within these modern operations human decision-making and human behaviour comprise a much more important part compared to the cold-war scenarios. The objectives of a military operation nowadays are often about reducing the tension in a conflict, while the earlier objectives were concerned on attrition. This means that the relative importance between technology and human behaviour has changed a lot, in order to determine success or not in a military operation.

Agent based models represent an alternative way to describe military operations. Still we talk about simulation models, but the agent based models typically put the human decision making in focus at the expense of high fidelity within technology representations. Another difference is the input level: Agent based models apply the input to describe each agent (i.e. low level), while the higher level behaviour constitutes the output from the model. On the other hand, traditional simulation models typically involve scripted behaviour which means that the top level behaviour is given by the input parameters.

So far FFI has not applied agent based models within Operations Research. Nevertheless, a lot of similar organizations do, and this report describes a variety of their applications. The trend found within these applications tells that the most promising ongoing activities are focused on human centric applications, i.e. applications were human behaviour and human decision making are deliberately represented.

# Contents

# 1 Introduction

This report is prepared by the FFI project 1004 GOAL. The aim of the report is to give an introduction to Agent Based Modelling and Simulation (ABMS) and a discussion of the applicability of this simulation technique to typical operations research (OR) problems analysed at FFI.

Why looking at ABMS? After the end of the cold war there has been an increased emphasise on low intensity conflicts. The Norwegian armed forces are and have been involved in several operations abroad in different coalitions (NATO and UN). The conflicts are characterised by a wide variety of tasks including peace support operations (PSO), counter terrorism, humanitarian assistance and various support to civilian authorities. Common features of these operations are an extended cooperation with non-governmental organisations (NGO), civilian authorities, etc. The threat is more diffuse and asymmetric and there are usually groups of people with different attitudes and agendas where decisions made by individuals are important. Hence, political, economical, sociological, cultural and psychological factors play a more predominant role in these operations.

The degree of success of these operations are usually not measured as the amount of damage inflicted on the adversary, but rather our ability to provide security to civilians and the success of state building after a (military) conflict. Hence, it is more difficult to deduce good Measures of Effectiveness (MOE) and other quantifiable criteria for measuring the degree of success of an operation. This contrasts to more traditional military operations emphasising territorial defence involving huge military forces, and where the enemy to a large extent were known beforehand. These features, among others, indicate that modern military operations have many features in common with complex adaptive systems [1]. There is a lack of good simulation techniques that captures relevant aspects of complexity[1] and human behaviour such as interaction, cooperation and adaptability leading to emergent behaviour such as self organisation and reorganisation. The purpose of this study is to take a closer look at ABMS to see if this simulation technique can support analysis of modern military operations, and whether it provides a complementary method to traditional simulation techniques such as discrete event simulation, system dynamics and static Monte Carlo simulations.

The content of this study is mainly based on a review of relevant literature, contact with other research communities and to some extent own experiences with applying ABMS. ABMS is a wide research field – from emphasising artificial intelligence to studies of complex adaptive systems (CAS). This study deals with CAS.

Chapter 2 defines core elements like ABMS, while chapter 3 capture a survey of other organisations experiences on ABMS. Chapter 4 introduces the crucial technique Data farming,

[1] The term complexity is related to the number of interactions between the elements constituting the system.

which enables the construction of reliable response surfaces. Chapter 5 lists some important venues (conferences etc) to learn more about ABMS, while chapter 6 indicates some trends for ABMS within OR. Finally chapter 7 concludes the report.

## 2 Definitions and Concepts

This chapter describes ABMS and important concepts in this context. No universal agreements (or definitions) on these topics exist, so the information is more like "common sense". The description is cited from [2]. Similar descriptions are found for instance from [3].

*"...In their most basic form, agents are software objects that perceive their environment through sensors and act on that environment [4]. Agents may be able to communicate directly with other agents, are driven by a set of tendencies in the form of individual objectives or satisfactions, possess resources of their own, are capable of perceiving their environment, possess skills, and whose behavior tends towards satisfying its user-defined objectives [5]. In short, an agent can sense their environment, communicate with other agents, build perceptions, make decisions, and take actions in an attempt to simultaneously satisfy multiple objectives. ABSs are based on the idea that [it] is possible to represent in computerized form the behavior of entities which are active in the world, and that it is thus possible to represent an emergent collective behavior that results from the interactions of an assembly of autonomous agents [5]. ..."*

As can be seen from this citation, ABMS in this context means simulation models where many autonomous agents act and interact in an environment. Other related research fields are Multi Agent Systems (MAS) [3] and Complex Adaptive Systems (CAS) [1]. Notice that almost every simulation model involves agents, e.g. the pilot in a fighter aircraft simulation model. Such a model is clearly not within our ABMS definition, because the agents constitute only a minor part of the model.

The ABMS approach is a *bottom-up* approach in contrast to more traditional simulation techniques, which normally follows a top-down approach. The top-down approach often includes a high-level scripted plan, which encompasses the simulation. For ABMS, nothing is scripted, and the simulation is forced only by the agent's goals and desires. Within ABMS, individuals and groups of individuals have their own wishes and desires simulated in an environment. They collect and exchange information and decide how to act. This may give rise to patterns that could be observed on an aggregated level, also called *emergent behaviour*.

*Object-oriented programming* is fundamental for ABMS – all the agents are in a software view, objects. On the other hand, ABMS is a small subset within the area of object-oriented simulation models. As can be seen from the definition above, ABMS is characterized by simulating agents together in MAS. The output is found in the emergent macro level behaviour while the input is placed within each agent at the micro level. In this way, ABMS is constituted by a set of interacting agents.

The agents are typically defined by many "soft" attributes (e.g. human desires). These attributes do not represent physical parameters like *p(kill)*, etc. This is a result of the idea of *distillations*, where only the most important factors are represented down to a certain level. A lot of these factors typically represent *human behaviour (human decision making)*, i.e. soft attributes. This seems to be one of the most promising features for ABMS within military OR, where up to now the representation of attributes other than hard ones (e.g. p(kill), p(hit), sensor range, etc) is considered to be challenging.

# 3 Experiences on ABMS

Many research agencies have within the last ten years spent resources on ABMS research. FFI is currently concerned about these experiences in order to learn from them. In this chapter we will list some of the most relevant set of these experiences. The list follows in chapter 3.1 below and is intended to represent the spectrum of application areas. In chapter 3.2 some own observations on the applications are given.

## 3.1 Some applications

*Impact of Degraded Communications in the U.S. Army's Future Force* [2]
In this paper an ABMS application on command and control (C2) is presented. The question is how degraded communication affects the army in the future. To be able to focus experimentation efforts involving high-resolution physics-based models was crucial, and ABMS was suggested to be appropriate for this. MANA[2] was used as the software tool because it facilitates quickly constructing and exploring of new scenarios. To keep the model simple, for example the detection was modelled by use of cookie-cutter algorithms modified by line-of-sight algorithms. On the other hand, jamming on own communication is represented (often a neglected factor in a simulation model) and the model provides lots of findings. One of the key findings is that the communication range imposes the highest sensitivity on the simulation output.

*Unmanned Surface Vehicles* [2]
The US Navy is considering the use of Unmanned Surface Vehicles to reduce risk to personnel in maritime interdiction operations, and to conduct intelligence, surveillance and reconnaissance, and force protection missions. This paper describes ABMS used to assess benefits and shortcomings of adding USV's to the fleet. The aim of this study is to both support the procurement decision makers directly but also to focus field tests and further research. The model used (Pythagoras[3]) is able to capture the factors of interest, i.e. number of contacts, threat density, traffic patterns, sea state, platform endurance, speed, detection range. Soft agent rules (e.g. a desire to do something) are considered to do a better job mimicking the sometimes chaotic nature of a combat, than hard rules (e.g. a logical "if-then-else" statement). Data farming was applied in

[2] *MANA* (Map Aware Non-Uniform Automata) is a simulation model developed for the New Zealand Army and Defence force by Defence Operational Technology Support Establishment (DOTSE).
[3] *Pythagoras* is an agent based simulation tool developed within Project Albert, a US Marine Corps sponsored international initiative focusing on human factors in military operations.

combination with regression trees, in order to investigate the impact from the factors.

*Squad-Size Exploration* [2]
The objectives of the experiment were to provide pre analysis insights in the issues of reducing the US Army infantry squad from 12 to 9 soldiers and to test the appropriateness of ABMS as a precursor to executing high-resolution simulation models. The models MANA and Pythagoras were both applied in parallel and finally a third high-resolution model (JANUS) was applied. In this case the ABMSs did not represent human behavior – only physical characteristics were taken into account. The two ABMS' were applied on an experimental design of 16 factors. Then JANUS was applied within the region of potentially most interest, found from the ABMS, where the number of factors was reduced to 7. This methodology proved to be effective, i.e. an initial exploratory analysis by means of ABMS which enabled a more focused follow-on high resolution model.

*Election processes in Peace Support Operations* [6]
This is a traditional application of the tool PAX[4], developed by EADS Germany. The model is specialized to represent election situations, as a part of a Peace Support Operation (PSO). Typical MOEs are escalation among the agents (i.e. soldiers, civilian people); the number of votes executed; average fear among a civilian group of people. It is reasonable to focus on the civilian people and their anger, fear, etc, in a PSO, because in most cases the objective of the military operation is to deescalate aggression amongst groups of civilians. In this specific application the objectives are to give every civilian a chance to vote, minimize own losses and prevent violence.

*Application of the MANA model to operations in the East Timor* [7]
This was a real situation with objective to do a search operation in a village. The commander of the operation was concerned about how to pursue the search, and he considered MANA to be an applicable tool for answering the question: What is the most effective way to conduct a search operation? The model did not consider all the aspects of the operation, but still the commander and his staff revealed that the exercise of setting the scenarios in MANA was highly beneficial.

At the Project Albert International Workshop #12, 2006 [8], there were a total number of 12 working groups, spread over a diversity of applications areas. These are summarized in table 3.1 below. This table provides an idea on a few current ABMS activities. As can be seen from the table, still some traditional equipment centric applications are found (#3 and #12). On the other hand a substantial amount of the applications are found within low intensity operations (#1, #2, #4, #7). Also, some interesting applications on processing of information are seen (#5, #6, #8, # 9).

| *#* | *Topic* | *Team leader* | *Tool* |
|---|---|---|---|
| 1 | Peace Support Operations | NPS / USMC | Pythagoras |
| 2 | Emergency Response To A Crisis | NPS / USA | Pythagoras |

[4] PAX is an agent-based modeling and simulation environment, developed by EADS, Germany, see also [6].

| | | | |
|---|---|---|---|
| 3 | Supporting Marine Air Ground Task Force w/Ground Based Fire Support | NPS / USMC | MANA |
| 4 | Exploring Requirements Of Non-Lethal Capabilities in a Maritime Environment | NPS / USN | MANA |
| 5 | Effects of Misinformation (alternative techniques in representing cognitive and collaborative processes, to facilitate exploration of the effects of such variables as expertise, information overload, and misinformation.) | Evidence Based Research (EBR), USA | NetLogo[5] |
| 6 | Combat ID | TNO – The Netherlands | Several models |
| 7 | Peace Support Operations (Check Point Scenario) | German Army Training, Doctrine and Army Development Command | PAX |
| 8 | Know How Management on Sensor Side - Investigating effects of an intelligent sensor on the mission success | Federal Office of Defence Technology and Procurement, Germany | ? |
| 9 | Communication Aspects in Urban Operations | German Armed Forces | ITSim |
| 10 | Effect Based Planning / Interactive Visualization | FHS/Sweden | Visual Interactive Language |
| 11 | Dynamic Decision Networks and MANA | USMA / USA | MANA |
| 12 | Future Combat Systems | NPS / USA | Pythagoras |

Table 3.1 *The working groups at PAIW 12, described by the topic, main actor and model applied*

*The perfect match for Virtual Combat ID experiments* [9]
In this effort, TNO is concerned about fratricide (i.e. blue on blue engagements) problems. They want to investigate the impact of varying situational awareness, target identification, human factors and TTCP (Tactics, Techniques and Procedures) under different scenarios on mission level combat effectiveness. The effort was represented through working groups at both PAIW12 [8] and IDFW13 [10]. Parts of the Dutch project are found within a US dominated experiment called “Coalition Combat ID Advanced Technology Demonstrator (CCID ACTD)”. At the end of IDFW13, TNO concluded that neither MANA nor other similar ABMS tools are flexible enough for their problem, and they plan to implement the problem in a programming language like Java or similar. The most important thing to represent in their model was varying situation awareness

[5] NetLogo is a multi-agent programmable modeling environment, coming from North Western University, USA.

and information filtering, which again is hard to represent deliberately in MANA.

*An analysis of combined arms teaming for the Australian defence force* [11]
This is about finding the best capabilities within Australian land forces. The analysis studies the relationship between the capabilities of the land force and the fundamental characteristics, attributes and skills inherent to parties within the force. Six core skills are identified: communication, detection, lethality, mobility, protection and sustainment. Each agent has an individual performance level within each of the skills. Interpretation of these attributes into physical systems is considered to be difficult. A way of dealing with this is discussed, but this also requires that terrain, vegetation and elevation are added to the model. Instead of data farming, they use evolutionary algorithms to explore the solution space. The analysis concludes that interesting relationships among the attributes are found and discusses these findings. The most important attribute was found to be detection.

*Complex science for a complex world* [12]
Here some Australian researchers consider ABMS within a broad range of applications. The following interesting experiences are stated:

*"…These systems have facilitated the analysis and understanding of combat, for example, using MANA to explore factors for success in conflict (Boswell et al. 2003). They offer an opportunity to analyse the behaviours that we would intuitively expect on the battlefield. Through the use of these systems, people are able to gain understanding of the overall shape of a battle and what factors are playing key roles in determining the outcome of a battle. However, in our opinion, current ABDs [Agent Based Distillations] are facing several shortcomings:*

- *Hard to validate and verify. System behaviours emerge from simple low level rules in any CAS. In current ABDs, agents are programmed without an underlying theoretically sound software architecture. Therefore, it is very difficult to validate and verify them.*
- *No reasoning during the simulation. Due to the high degree of nonlinear interaction between agents, it is impossible to reason at the agent level, which makes it hard to understand the results of the whole simulation.*
- *Can be a computationally expensive exercise in some systems. This is either because of a bad design, unnecessary fidelity, or fancy tools without proper modelling.*
- *No connection between tactic and strategy. Existing ABDs are developed either on the reactive agent architecture, which focuses on tactics, or on the BDI (Belief-Desire-Intention) architecture, which focuses on strategies (Wooldridge and Jennings 1995; Nwana 1996; Sycara 1998; Wooldridge 1999). There is almost no interaction between tactics and strategies being modelled by existing ABDs.*
- *Hard to capture the underlying structural interaction between agents. Although existing ABDs embed the structural interaction between agents, there is no explicit model for such interactions. It is hard for the user to capture these interactions during the simulation, which is a crucial point of a CAS.*
- *Difficulty in application to complexity. Current ABDs are based on conventional military tactics and tend not to be approached from an overarching systems view. Concepts such*

*as NCW, with its inherent complexity and interdependency, present challenges to identifying correct inputs at the entity level. Thus, techniques addressing higher level manipulations must be employed….”*

These shortcomings are important to be aware of. Nevertheless, the good way to utilize these shortcomings is to have them in mind when deciding upon where to apply ABMS.

### 3.2 Observations on the applications

The examples on ABMS applications above represent a broad range – some are equipment centric and others are focused on softer issues (human centric). Traditionally the OR simulation models have been focused on comparative analyses in procurement studies, something that is evident from the list above. On the other hand, a few agencies (EADS/GE, TNO/NL, DRDC/CA) have started to apply ABMS within representation of human behaviour, human (imperfect) information processing and cognitive processes. Some of these activities are not yet materialized into papers but they represent a trend from equipment centric applications to human behaviour centric applications.

## 4 Data farming

This methodology [13] is developed by *Project Albert, United States Marine Corps*, and enables an exploration of the output surface (or response surface) of a simulation model. The idea of data farming is applicable to all kinds of simulation models, but is especially applicable for the ABMS, which typically possess fast execution. The level of details is low (coarse grained), and the accuracy of input parameters are normally low.

Data farming makes use of high performance computers to perform many runs of the simulation model. In this way the output surface can be explored. Traditionally these kinds of explorations have been performed by varying one or maximally two parameters simultaneously, while the rest of the parameters are fixed (also called gridded design). This only explores a very small portion of the surface. On the other hand, by means of data farming the simulated points on the surface is spread maximally, in order to explore the whole “landscape”. Having this output surface at hand, typically made by thousands or million replications, trends and general insight can be built of the modelled problem.

Data farming is related to the statistician field called *Design of Experiment* or *Experimental design*.

## 5 ABMS arenas

The application of agent based models within military OR-applications is not a mature area. A lot of nations and agencies have spent resources to explore these techniques and still many of them continue to test the applicability of ABMS. Along these lines, it is obvious that progress within this field for FFI heavily depends upon international collaboration. Below a set of arenas for collaboration are depicted.

*Conferences*

- *Winter Simulation Conference* is a US conference in the field of system simulation, focused on discrete-event simulation and combined discrete-continuous simulation
- *International Data Farming Workshop* is a US conducted workshop with a lot of participants from other nations. The Naval Postgraduate School, USA chairs this activity. The topics of the workshop are all concerned about ABMS

*Journals*

Many of the OR journals are relevant arenas for ABMS, where for instance *Journal of the Operational Research Society* and *European Journal of Operational Research* constitutes good choices. Other journals are found in [14].

*Research establishments*

- EADS, Defence and Security, Germany
- Defence Technology Agency, Australia
- Naval Postgraduate School, USA
- Australian National University

# 6 The future for ABMS

The aim of this study is to investigate the OR potential of ABMS. A lot of papers are considered and also we have attended two workshops [8], [10]. From these arenas we can observe that some agencies have spent large resources within this field without being convinced. The comprehensive example in this context is US Marine Corps. Having spent almost ten years on ABMS through Project Albert, they have now ended this activity. On the other hand, several German actors are currently putting a lot of effort into ABMS, which indicate that they have made the opposite conclusion.

Another interesting trend is found within human factors applications. The German model PAX is focused on the representation of cognitive processes and TNO are currently dealing with what they call “Social simulation” within the fields of crowds and crowd control. This is also mentioned in [12]. This trend is also intuitive in the way that the ABMS variables do have a “soft” nature and is not very appropriate for dealing with physically based variables.

# 7 Applicability of ABMS within OR at FFI

This chapter concludes the report and gives some recommendations for dealing with ABMS at FFI.

## 7.1 ABMS's role in the OR process

The OR process is initiated by formulating the problems to be addressed in the analysis. Only when the problems are identified and precisely formulated it is sensible to discuss what kind of methods that is most suitable to analyse the problems. Simulation is a frequently applied technique both with regard to gain understanding of the system (model and simulate a system) and for calculating consequences of various decisions with regard to the system. As illustrated in figure 7.1 ABMS distillations may support different phases of a typical OR process. However, our opinion is that ABMS is most applicable in the first phases of the analysis, i.e. to gain insight into the problem domain by for instance a pre-analysis aiming to uncover critical parameters in the system. An example can be to find the most important factors affecting the behaviour of a crowd of people if something (bad) happens.

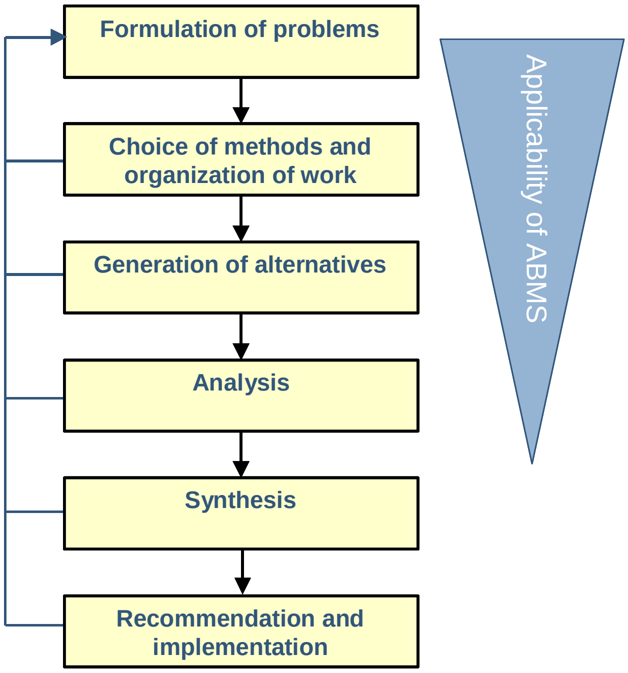


Figure 7.1 *The OR process.*

As explained in the introduction, analysing modern military operations normally requires a broader focus on the situation – human factors and human behaviour are more predominant in these operations than in traditional cold war scenarios. It is fair to claim that problems have become more multi-dimensional – thus, knowledge about a wider spectrum of analysis methods is required. The strength of ABMS is to simulate human behaviour and human interactions; hence ABMS is well suited to explore various human aspects of the system under consideration.

## 7.2 Feasibility of ABMS within OR application areas

The aim of this report is to investigate other agencies experiences on ABMS within military OR, and learn from them. Chapter 3 summarizes a set of representative applications of ABMS. Now we want to analyze and categorize these applications into three fields. Finally, these fields of application will be used as a discussion framework for answering the question "What is the applicability of ABMS within OR at FFI?"

The suggested set of application areas are: Planning in the theatre (decision support within COA), Analysis and Training. Notice that training is traditionally not considered to be a part of OR. Despite this, some interesting ABMS applications are found within this area, and of this we include the category. The areas will now be presented and discussed.

*Planning in the theatre*
This is basically decision support in front of or within a military operation. From the ABMS basic features, i.e. quickly defined distillation models capturing only some aggregated factors, this ought to be a suitable application. The model GAMMA [15] is built for this purpose, and also some of the most successful applications of the model MANA are based on just this kind of application.

*Analysis*
This is the broadest application area and captures several subfields, amongst decision support for procurement; development of techniques, tactics and procedures; evaluation. The example of Unmanned Surface Vehicles above is a classical procurement application in an early phase, where the Armed forces need help on the assessment of benefits and shortcomings of a new platform. This is a good example of ABMS applications, where the feature of getting insight into a new problem domain before digging into the high-resolution physics-based models is utilized. Another example is constituted by the model PAX where typical applications involve variations of the tactics within the military force, and looking for the response on the civilian people's behaviour. In this context, the representation of human behaviour, especially for the civilians but also for the military force is a crucial part of both the reality and the PAX model. This is a type of problems not captured by traditional OR models. However, ABMS seems to be a promising tool.

*Training*
The number of applications within this area is so far few. Nevertheless, one example, based on the model PAX, use ABMS to simulate the operations environment typically a soldier can be faced with. This is already a large area for simulation models, and for instance the Norwegian Army has procured advanced facilities for training up to the company level. The German model PAX is extended into a 3D visualization version to capture a realistic urban warfare environment, where a single soldier can exercise in a quite realistic mode.

These three application areas are quite distinct, but also a lot of commonalities are found. For instance, a model for training purposes can very well be used within procurement questions. So far, the Operations research activities at FFI are mainly found within the second category – analysis. From the discussion above this seems to be a proper starting point for FFI to test ABMS' applicability.

## 7.3 Conclusion

After the end of the cold war, military operations are more and more often found within Peace

Support Operations (PSO). High intensity warfare is still considered to be relevant, but more and more of the focus is moved into low intensity PSO. These operations do not involve heavy weapon usage, and the objective is never to defeat the enemy. Instead, the old attrition based objectives are replaced by stability- and security objectives. This again makes the success of the military operation nowadays relatively more sensitive to human decision making than to platform (tanks, fighter aircraft, frigates, etc) capabilities.

Within Operations research, simulation of military operations has for several purposes been an important activity. Traditionally this is pursued by building software models representing force on force attrition based warfare, where human decision-making is scripted. Within this tradition, the models were based on physical-based parameters. Today's operations are much more human centric and it's crucial to represent this decision making inside the models.

Measures of effectiveness (MOE's) are important when analyzing system performance. Especially, when building models, the actual set of MOE's depicts what the model should represent and the needed input data. Again, when the objectives of the military operations are changed, and hence the MOE's, new kind of simulation models are required.

These observations motivate for ABMS. The agents are well suited for representing soft issues like human decision making. There is no scripting of this behaviour and the approach is bottom up. This approach enables human centric models where interaction amongst agents is well represented. At the heart of ABMS is found emergent behaviour – this macro behaviour is an important part of the output which is not a part of the input.

OR problems typically do have several aspects – some are of technical nature and others deal with human behaviour. Thus, several methods are needed in order to analyse these aspects. Traditional models focused on the technical aspects will for sure exist also in the future. On the other hand, ABMS is suited for addressing problems involving human behaviour. Hence we argue that ABMS and traditional OR simulation models are complementary.

ABMS is tested and developed within military applications for the last 10 – 15 years. A lot of promising areas are depicted, but also a lot of unsatisfactory results are seen. Our observations tell that exploration of ABMS within all types of OR are found, but the human centric applications seem to be the most promising ones. Validation is another important factor in this context. Experiences with ABMS show that this is hard to accomplish. This indicates that an ABMS application where the only objective is to calculate MOE's is maybe not the best idea. Instead, an application in an early state of the analysis, where the objective is to identify the factors affecting the output at most, seems promising.

With these observations, ABMS constitutes a promising tool within today's military operations. On the other hand, ABMS is not a tool for all categories of problems: The most promising ABMS application areas are found within human centric problems (i.e. human decision making is important for the problem) found in an early state of the OR analysis.

## Appendix A Abbreviations

| | |
|---|---|
| ABD | Agent Based Distillation |
| ABMS | Agent Based Modeling and Simulation |
| ABS | Agent Based Simulation |
| BDI | Belief Desire Intention |
| CAS | Complex Adaptive System |
| COA | Course of Action |
| C2 | Command and Control |
| DRDC | Defence Research and Development Canada |
| EADS | European Aeronautic Defence and Space Company |
| FHS | The Swedish National Defence College |
| IDFW 13 | International Data Farming Workshop 13 |
| MAS | Multi Agent System |
| MOE | Measures of Effectiveness |
| NGO | Non-Governmental Organisation |
| NPS | Naval Postgraduate School, USA |
| OR | Operations Research |
| PAIW 12 | Project Albert International Workshop 12 |
| PSO | Peace Support Operations |
| TNO | Netherlands Organisation for Applied Scientific Research |
| USA | United States Army |
| USMA | United States Military Academy, West Point New York |
| USMC | United States Marine Corps |
| USN | United States Navy |
| USV | Unmanned Surface Vehicle |

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