MODELLING AND SIMULATION IN DEFENCE

Klaus NIEMEYER

Introduction

The use of modelling and simulation (M&S) is becoming more pervasive throughout the NATO defence environment. Simulation models use a variety of techniques, which have evolved from system dynamics, information science and operations research (OR). There are closed simulations, without human interaction, which are used primarily for research and analysis. At the other end of the spectrum there are interactive simulations with considerably active participation of operators performing, in general, the human decision making process. The latter type has been the mainstay of experimental gaming or war gaming in the past, but is now finding increasing application in the computer-assisted exercises (CAX). Thus, it can be argued that, not only are simulation models and applications expanding, but that their associated techniques can be applied across the full spectrum of functional activities of armed forces.

While the use of modelling and simulation for military purposes is expanding, recent work by the NATO Steering Group for Modelling and Simulation has demonstrated that most applications in the NATO nations have been developed by individual organisations to meet the explicit needs of a particular user community; are not integral to operational systems; take too long to build and cost too much; can not be used in concert and are not fully validated. The consequence was the proposal to develop and apply standards and interoperability procedures as provided by the High Level Architecture (HLA).[1]

M&S is an essential component for any intellectual behaviour. Human knowledge and intellect are based on the ability to create and manipulate models either cognitive or concrete, as an individual or in groups. The collection of information and the systematic creation of an image, model paradigm or construction, which represents a part of the real environment, are fundamental for the development of intellect. Only by experimenting or manipulating these representations in a goal-oriented, more or less systematic approach, it is possible to determine those solutions, which comply with the desired objectives. The intellectual search for best solutions is always based on *trial and error* application of models. Learning is possible only by making mistakes but this should not be done with a real system of high value or with processes, leading to catastrophic situations. Therefore, only models, which permit the necessary simulations and experiments, are means for finding best solutions.

With the quantum leap in the technical and methodological evolution characterised by digital information systems, modelling and simulation is contributing in high synergy to this development. Although the principles of experimenting in knowledge gathering on the basis of replicas of real systems are as old as the human intellect, models and simulations with digital computers have developed during the last few decades. The disciplines of natural sciences, in particular those with a quantitative and logical approach to fact finding, as well as the engineering disciplines, developed a huge amount of numerical and logical models that are operated on digital computers.

The essence of simulation is the development and application of explicitly formulated models, which are executed on computers. These models enable reproducible results to be generated at anytime in so-called computational experiments. These are achieved with many parameter variations and testing of assumptions and, thus, are accessible for discussion and change. The models are structured from mathematical and logical relationships, which are based on technical, physical or social insights and theories. A model can be seen as a replica of an existing perceptible system or as a precursor of a foreseeable system in the planning stages. The model enables the simulation of the system considered and the analysis of parameters, assumptions and arguments to be handled. It enables insights into sensitive areas, trends and interrelationships between parameters.

It can be stated that models and simulations are indeed the most sophisticated method of information processing and may be regarded as part of hybrid intelligence. Considering the power of existing computer technologies, the performance of which have increased far beyond all expectations during the last few decades and has so far hardly been exploited, as well as the capabilities of associated software and information systems tools, it becomes clear that models and simulations have an enormous potential with regard to thinking processes. On account of the models, the simulations have a rational basis, on which a profitable discussion may be carried out. Due to model structuring it is possible to define and control the complex relations of the real world. In a superior way, human decision-making is still given the important function of taking the responsibility, but irrationalities due to the limited human information processing capacity are eliminated. Simulations offer the possibility of analysing the systems of the future, which might be introduced one day. On account of the direct decision-making activity in these simulated systems, experimental games provide planners with information about the future. They are catalysts for group intelligence, which can define, evaluate and manipulate complex system relationships. Only in this manner the problems of the future are likely to be treated consciously and rationally.

Theory of Modelling

Operations Research (OR) was first recognised as a discipline in World War II, following use of various techniques to optimise planning of military operations.

In 1950, Morse and Kimball defined OR as:[2]

> "a scientific method of providing executive administrators with a quantitative basis for decisions regarding the operations under their control."

OR techniques have developed greatly over the years. Simulation has become a major tool. Simulation languages were developed in the early 1960s that embodied already various features found in modern computer software (e.g. object-oriented programming, list structures, and event handling). Possibilities of development of OR techniques have been greatly enhanced by the wide availability of powerful computers.

The terms *simulation* and *model* are often used. They are, however, frequently not adequately defined. Definitions, if offered, tend to be imprecise. They may increase confusion rather than aid comprehension, like the categorisation of simulations as *virtual*, *life* and *constructive* simulations.[3]

A model can be defined in terms of typical attributes. In this sense, a model:

- will have been developed to allow a clearly stated *objective* to be achieved
- will *represent another entity* (which may be real-world or another model)
- will be an *aggregated* representation of that other entity (reduction in complexity)
- will be intended to aid *perception* (past) or *anticipation* (future)
- may be either *conceptual* or *concrete*.

This list is not intended to be comprehensive, but only to cover the most important attributes of a model.

According to this definition, a plan may be regarded as a model, prepared with the objective of aiding the determination of an optimal approach to a future operation. The plan will embody an aggregated representation of the situation in which this operation is going to be conducted. It can be made concrete, since it can be documented and made accessible to others, not only to its creator.

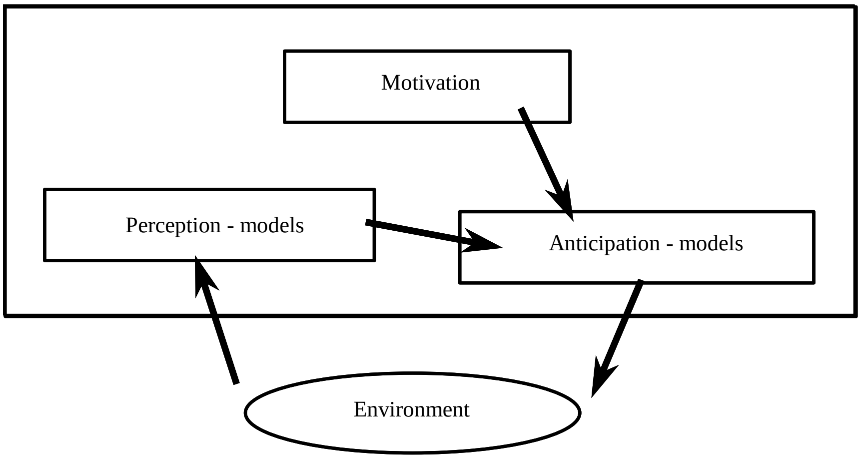

Figure 1: Intellectual System.

Simulation can also be regarded as a model, embodying an aggregated representation of the dynamics of a process. In such a model, time is the essential variable. In an interactive simulation, human participants perform real-world functions. A training exercise is one example. The objective of a training exercise is to develop participants' skills. An experimental game may also provide an example of interactive simulation. The objective in playing such a game would be to allow participants to determine the effects of altering at least one variable.

Models, particularly simulation models, can be regarded as essential elements in any intellectual system. Through intellectual systems that embody perception models (equivalent to learning processes) and anticipation models (equivalent to plans) environments can be manipulated and environmental changes anticipated (see Figure 1). The model of this intellectual system can be interpreted as an agent within the advanced information systems technology or the research domain of artificial intelligence.

Attributes of Models

Any model is by definition an image or representation of an original, the objects of the real system (see Figure 2). Therefore, models are always *virtual*. Any model is also a *construct* developed or created by humans or, more generally, by an intelligent system for a given purpose, e.g. experimentation.[4]

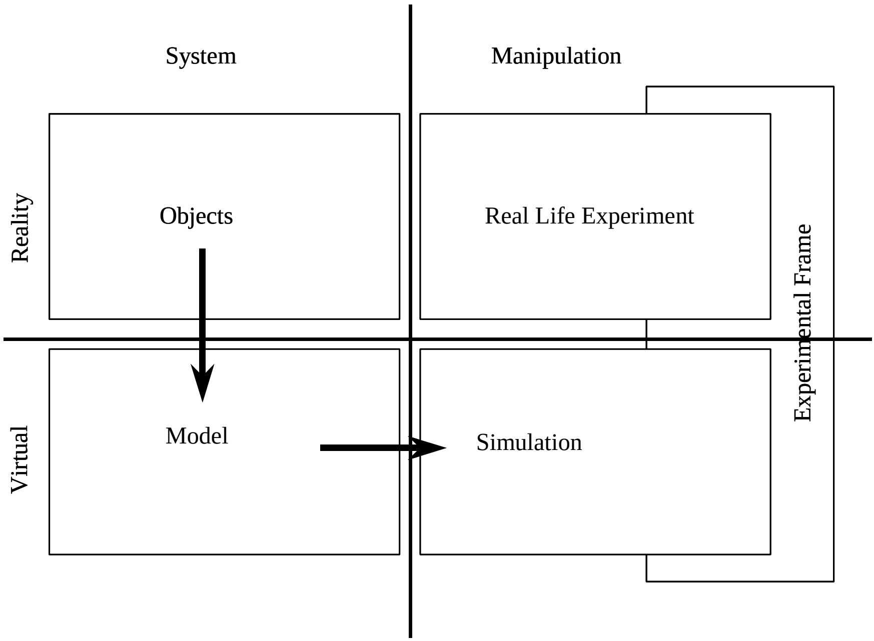

Figure 2: Modelling and Simulation.

Simulation is seen as an experimental set-up in order to perceive or anticipate the dynamics and the behaviour of the systems. Any simulation uses a model, which is designed for that purpose. Important characteristics of models as basis for simulations are:

- purpose
- relationship between model and original
- reduction of complexity.

Models are substitutes for the original for defined, cognisant or perceiving and acting, model-using subjects (intelligent systems) within defined time frames and by constraints on given mental or real actions. The most determining principle of the purpose is that models are developed and applied in order to fulfill given goals or motivations.[5]

Either a model is seen as representation of its original, or it is seen as prototype for a future construction. Thus, there is a certain relationship between a model and its original in reality or between the future construction and its model in reality. The generation of models is a directed process in time; hence the model-original relationship can be separated into two aspects:[6]

- the model is the *representation* or the image of the original
- the model is the *prototype* for a future construction.

Reduction of complexity means that models simplify the original or the future construction in order to reduce the *noise* of the reality, to systematise facts, or to transmit knowledge and information. The model does not represent all attributes of the original. It represents only those attributes that are relevant or suitable for the creator/user of the model. Normally, only a few attributes, elements, or parameters are taken into consideration, namely those that are important for the desired purpose. The many attributes, elements, or parameters that have a *noise* effect, reduce the clarity of results, or have little relevance are not taken into consideration. A model is easier and less expensive to manipulate than the original or a construction.

The dominating attribute of a model design and its simulation application is the objective or motivation for this activity (see Figure 3). Typical objectives are:

- *research*, which creates new insights in the phenomena of activities, organisations, operations, planning, procedures, technologies, etc.
- development and *engineering*, which create new options for activities on the basis of the research insights. This includes assessment of options and identification of the best solutions and prototypes.
- *testing*, which adds *flavour* or *noise* in order to test the functionality and robustness of the solutions and prototypes in stress conditions.
- *training*/exercises, which enable humans to operate and control the developed and tested solutions in quasi-real conditions.

Figure 3 shows the principal evolutionary development of models.Starting with the research, a phenomena or system in reality can be analysed by separating the noise effects and isolate the core of the problem. This core can be modelled and simulated in order to obtain the manipulation and change needed for the formation and engineering of a new entity or prototype. By adding noise and the effects of the reality, testing and experimenting, and finally, training of humans in exercises is possible. This synthesis is fundamentally different from the analysis. Simulations and models are major tools within the full sequence of developments.

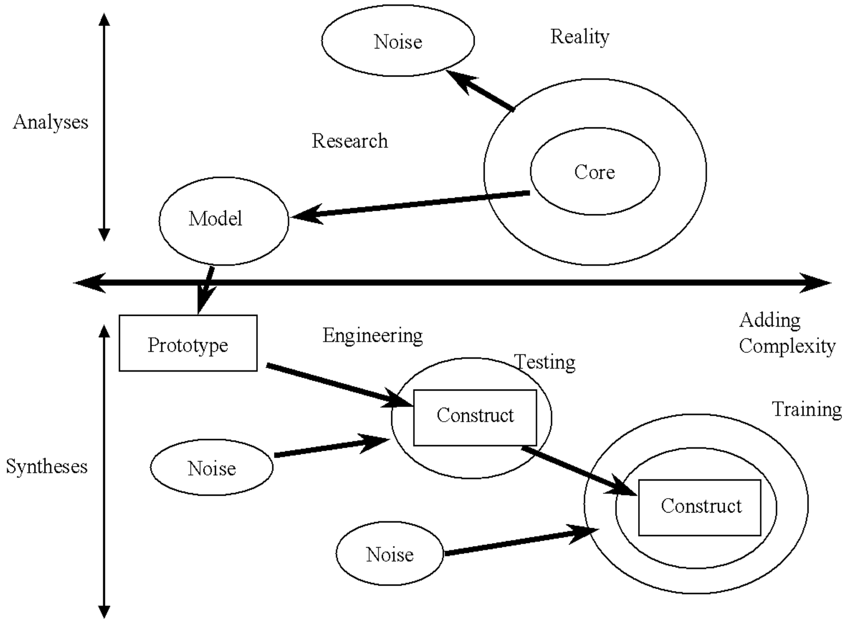

Figure 3: Evolution of Modelling and Simulation.

The objectives cannot be seen in isolation. There is a clear direction or sequence of activities. The training/exercises only make sense after *verification* of the solutions or prototypes in testing frameworks. Testing can only be done after selection of the best-developed and engineered solutions, which in turn is only possible on the basis of research insights. It is impossible to turn these sequences around, e.g. a training or exercise activity and framework is not a valid and useful approach for the research objective. The aim of the research activity is the identification of systematic insights, which can only be done by elimination of real-life noise. In training or exercises these are essential ingredients for the human trainees, since this represents the reality. The objectives of the simulations are, therefore, leading to and determining different model constructs.

Attributes of Simulations

Simulation is the dynamic application of the model that was designed for simulations. Any simulation is a representation of the system, which changes its state in time. Simulation constitutes a dynamic process in time. In any simulation, the following characteristics are important:

- Experimentation
- Dynamics
- Determination.

Simulation is an experiment on the basis of a suitable model (simulation model) and an experimental frame. The methods and principles of scientific experimentation in the implementation, application, and evaluation phases are fully applied in the case of research and analysis. The credibility and/or acceptability of the results are determined by the experimental frame, the purpose of the investigation, the model used, and the reproducibility of results. Time is the independent parameter in any simulation. From an initial state or situation, the time and state of the model are changed and advanced either continuously, in time steps or at given events until a final state has been reached (time-step simulation versus event simulation). The problem of time synchronisation has to be taken into consideration in certain applications, e.g. in simulators for training. The simulation is stochastic if relevant processes are based on random events. Starting from identical initial states, the random events produce significantly different final states within the reproduced simulations. A sample of simulation runs results in probability distribution of the final states. The simulation is deterministic if no relevant random events influence the processes. In this case, reproduced simulation runs should result in identical final states.

Interactive simulations are open to human operators who are able to interact with the model and to change parameters while the simulation is progressing. For analysis purposes or for testing of plans and procedures, this simulation is also known as experimental gaming (war gaming). For training purposes in command and control settings it is known as Computer Assisted Exercise (CAX). As games, like experiments, are rather expensive in comparison with closed simulations due to the integration of personnel (time and resources), the risk of committing errors must be reduced by careful planning in order to make the best use of time and resources. In this context, planning and evaluation of runs have to be particularly emphasised. It is frequently assumed that the restrictions on time, costs, personnel and resources do not allow an ideal experiment.

Model Categories

The models can be categorised and structured in the following types:

- Free-form games include dialectic exchange and discussion, brainstorming, the path-gaming methods or games in which conflicts, coalitions and even the rules are developed during the course of the game.
- Model games or war-games that work with computer models or are based on

rigid rules. The computer models are generally structured as simulation models, which represent the system to be played with. The model games are seen and designated as interactive or open simulations.

- Closed simulations which are intended to represent many functions as realistically as possible, in great detail. In closed simulations, in contrast to open simulations, human leadership and decision-making functions are represented not by human beings but by rule mechanisms and algorithms. The advanced technique of agent-based modelling falls also within this category.
- Analytical, statistical and operations research procedures, which include expected value models, optimisation techniques, and so on. The analytical procedures generally contain exclusively static elements.

Model Characteristics					
		Free Form Games	Interactive Simulation	Closed Simulation	Analytical Model
Components	Real, humans	x	x		
	Computer		x	x	x
Requirements	Resources	very high	high	low	very low
	Time	very high	high	low	very low
Attributes	Dynamics	x	x	x	
	Abstraction	low	low	average	high
	Reproducibility	no	low	high	high
	Transparency	low	high	high	low

A principle can be recognised for the model categories. This is of particular significance if architecture of models of different categories has to be developed:

- With an increasing degree of abstraction the models are in fact easier and quicker to handle, but depend on the results provided by the detailed models in order to represent the respective system level. This process can be seen as a methodological aggregation.
- With an increasing detail (less abstraction) the models are of higher fidelity, but evidently slower and more expensive. Thus, in the analysis phase, it is increasingly more difficult to cover an appropriate spectrum of analysis alternatives. For this reason, the number of possible alternatives can be limited with the more abstract models in order to investigate more precisely the most interesting ones, followed by the more detailed models.

In this way, the models supplement each other; no model is the replacement of another.

Interactive simulations, e.g. war games, are predominantly used where human leadership functions play an important role. This is necessary for the analysis of the defence system, as it is characterised decisively by the quality at military command and control in its effectiveness. Here the command and control process is perceived by real components of the system, the human commander himself.

When human decision-making, as well as the command and control processes in the interactive simulation, is successfully represented by corresponding modelling methods on the computer, the whole process is conducted in a closed form on the computer. In this sense, the command and control models are agents as defined in the research domain of artificial intelligence. The interactive application can be systematically used to research the command and control rules, which are needed for the decision-making logic or for modelling of the agent behaviour in the closed simulation.

With the rapid development of the information net technology and the associated software, the methodology of distributed simulations raised high interest. This methodology is supported by the standards of interoperability, e.g. HLA, and the idea of combining and synchronising independently developed simulation models for use in distributed exercises. Although this approach provides some interesting aspects for use in international or inter-organisational exercises, the disadvantages of not being able to control and understand the application and to interpret the results have to be considered as well.

Defence Applications

In the military domain, models have been primarily developed and applied in the areas of (see Figure 4):

- Defence Planning
- Development, engineering and acquisition of systems
- Training and exercises, and
- Operational planning.

Although these principal application areas require models which calculate the effects and resources for military forces, it is important to note that these areas are very different in the purpose of the application and, therefore, leading to models of quite different structures, as discussed in the evolution of modelling and simulation (Figure 3).

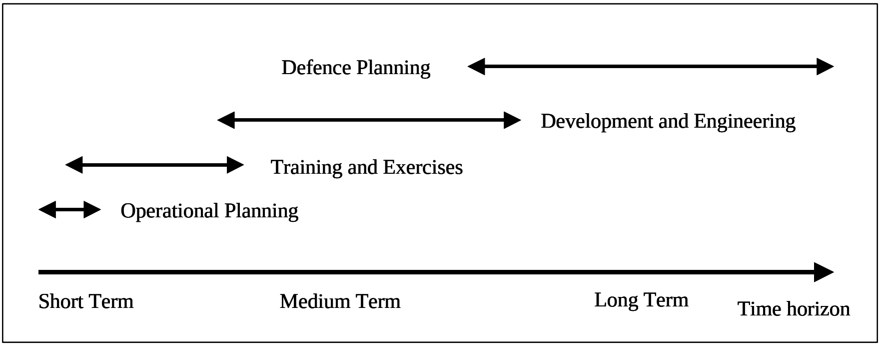

Figure 4: Military Application Areas.

Characteristics of Application Areas					
Application Areas	Time Horizon	Data Requirements	Scenarios	Reaction Capability	Objective
Defence Planning	Long term	Assumptions and estimates	Many	Very small	Robust Structures
Development of Systems	Medium term	Precise System Data	System related	Medium	Cost/effective solutions
Training and Exercises	Short term	Precise System and Environmental Data	Training related	High	Training of skills
Operational Planning	Immediate	Real Data	Real Situation	Very high	Optimal decisions and operations

Models for defence planning have to be able to calculate a huge variety of parameter variations in order to manage the uncertainties in the long-term future development and to analyse many options for the creation of robust structures. On the contrary, support in operational planning is based on situation with a given force structure and requires models with the capability of quick response and representation of real attributes and data. The objectives in the area of training and exercises are to train human operators or staff groups and, therefore, a quasi-realistic (virtual) environment has to be created with the noise and flavour of the real life. On the other hand, in developing and engineering of new systems it is important to manage the noise and the complexity of the system in order to create transparent and reproducible solutions.

Utility of modelling in the application areas				
Application Areas	Free Form Games	Interactive Simulations	Closed Simulations	Analytical Models
Defence Planning		Only for Testing	High	Very high
Development of Systems		Only for Testing	High	Very high
Training and Exercises	Limited	Very High (CAX)		
Operational Planning			High	Very high

The defence system, like any other complex live system or organism, requires steady adaptation. To this end, potential improvement options need to be continuously tested and compared with a view on their feasibility, effectiveness and robustness in a wide range of possible scenarios and taking into account all of the sensitive factors and their inter-dependence. However, as the human brain may only consider a limited number of system entities and interrelations simultaneously, modelling and simulation tools and methods become necessary to support the planning and structuring of forces. Since models permit account to be taken of the complex interactions of modern day combined arms combat and its synergistic weapon effects, simulation approaches provide the required basic instruments. Yet, it must be born in mind that any analysis has its limitations due to very practical reasons, such as the availability of data, time, and skilled personnel.

Further, it has to be considered that:

- The models are mathematical (logical, numerical) constructs for digital computers, which provide many kinds of human interfaces wherever appropriate,
- The models are operated in an experimental/procedural framework, which permits the systematic manipulation of inputs in relation to the objective of the simulation, and
- The models represent parts of the military system at several hierarchical levels, missions, functions, objectives, and within predefined constraints and environmental conditions/scenarios.

In what follows some important aspects for the areas of defence and operational planning will be discussed in more detail.

Military Structures

Large and complex systems, such as the Armed Forces, are always hierarchically organised. At low level, the system is physically identifiable in its components, such as men, weapons, equipment, and vehicles. These components are integrated into formations, which have a particular task to accomplish, although restricted in terms of location and time. The time resolution is of the order of minutes or even seconds since duels between modern weapon systems are generally decided in a relatively short time. The influence of the environment has a direct bearing, i.e. the outcome of a duel is dependent on the presence of a direct line of sight to the opponent. At a medium level, the system elements resemble the formations of the low level. These elements may be integrated into major units such as battalions, brigades, or divisions and they can undertake particular, yet wider ranging, targets and tasks. The time resolution at this level is usually of the order of hours as, in addition to the direct battle, some time is required to carry out additional functions, e.g. to take the appropriate command measures and to position the formations at the desired places. The results of a battle are determined by a large number of duels whereby it is sufficient to consider the terrain in its general features using appropriate maps. At high levels, the system is made up of the medium level units. The time resolution is in terms of days since, in addition to the combat operations at medium level, a wide variety of logistical, surveillance, command and control, preparation, support, and movement processes, all of which require time, are taking place.

It is important to define the level of simulation in the system since there are specific problems at each level. It is not possible, for instance, to create a simulation at the highest level on the basis of consideration of duels at the lowest level only.

To achieve an architectural structure for models, procedures and applications, order criteria have to be agreed, towards which the many possibilities of modelling should be oriented. As an example, here the system levels are structured in relation to the hierarchical structure of military forces as follows:

- Security system in long-term interaction between sociological, economic, ecological, political and military forces in an international context. The dimensions of time are measured in years.
- Security system in relatively short-term interaction between political and military forces in an international context for resolution of crisis. A military build-up of forces (mobilisation) falls in this category. The dimensions of time are measured in months.
- Military system of armed forces in an operation. The military area is a theatre or a region. The dimensions of time are measured in weeks.
- National armed forces, i.e. Army, Air Force and Navy, in typical sub-

scenarios of a major conflict or crisis. The dimensions of time are seen in terms of days.

- National major units or units of a respective Armed Force in typical (generic) sub-scenarios. The dimensions of time are measured in terms of hours.
- Weapon systems or individual functions at the lowest level. The dimensions of time are measured in terms of minutes.

Given this structure at various system levels, the following principles for architecture can be assumed, which are of great significance for model development and model applications.

- For a top down approach, the objectives and the assumptions at the lower level are derived from scenarios at the respective upper level.
- For a bottom up approach the input for the simulations can be aggregated from the results of the lower level, i.e. they can be so summarised that they represent sufficiently the variety of the respective micro-events.

In this way, the data flow can be defined as comprehensive model architecture.

Some aspects should always be considered for the assessment of the appropriate resolution of models for simulation. The applications should be adjusted to the particular problems at the respective levels. From a pragmatic point of view, the input and output data have to be manageable for the user, the modelling process has to be clear at least in general terms, and the data volume has to remain within the work limits of the users and the developers. The models can be constructed efficiently with modular and open software technology, e.g. object-oriented programming, if appropriate. Thus, it is possible to exchange simple, less detailed modules with more complex ones and vice versa. Given the availability of standard data structures and interfaces, such as HLA standard and agent-based modelling, comprehensive modular systems can be developed, as long as the resulting product can be kept under control. For models of higher levels of the system hierarchy it is necessary to develop procedures for aggregation of data from the detailed models of the respective lower hierarchical levels. This process demands from the user to have a relatively high abstraction capability and it is often not understood. However, as there are generally some overlaps between the hierarchical levels, it is possible to reciprocally check the model functions in an iterative manner.

The resolution of a model is to be understood as the process described by explicit state parameters or the element level of the modelled system. The greater the resolution of a model, the greater the variety of mathematical functions and the amount of necessary data and assumptions. Whereas pure conceptual models in most cases only have minor resolution, mathematical simulation models allow considerably greater resolution. On the other hand, a model that is too comprehensive and too complex cannot longer be handled due to the loss of transparency and reproducibility. This contradicts the intentional and deliberate simplification by eliminating factors, which are irrelevant to the objective. In the end, neither of the extremes, the all-intelligible trivial model and the all-inclusive no longer manageable overall model, is suitable for simulation. Another aspect of model development results from the fact that the evaluation of defence systems and even of individual components cannot be confined to one process level. For instance, duel models usually do not suffice to give enough information about the effectiveness of a weapon system. For example, the frequency and/or the importance of the respective duel situations or the availability of the weapon system must also be taken into consideration. Both parameters, however, closely depend on the next higher process level, in this case the combat or the operation. Thus, for example, the importance of the Air Force mission *Interdiction* (engagement of moving army formations by the Air Force) is not only reflected in the primary effect expressed in destroyed vehicles, or the secondary effect expressed in local disorganisation and march delay, but rather in the relief of defending in the point of the main effort of the battle. In this case, simulation models that cover several levels are needed.

Military Functional Areas and Phases of Operations

Military operations can be regarded as groups of processes occurring simultaneously or in sequence (see Figure 5). There is a wide range of processes involved in planning and executing military operations, both for generic peacetime planning and for contingency operational planning. Some of these are shown in Figure 5. They interact in complex ways and require stringent management. Intelligence in the military sense is concerned with identifying threats and stimulating political decision-making processes. In peacetime, generic plans are made to ensure readiness for operational planning if a crisis situation arises. Outcomes of operational planning form inputs for political decision-making, and govern military deployment to crisis areas. Deployment of well-trained forces and subsequent preparation for their possible future employment may deter a potential aggressor. If deterrence works, no further employment of forces may be required. Re-deployment of forces may subsequently be possible.

Simulation can be used in relation to any of these processes, to arrive at optimal solutions. Use of simulation is especially valuable in deriving solutions in the face of frequently changing circumstances.

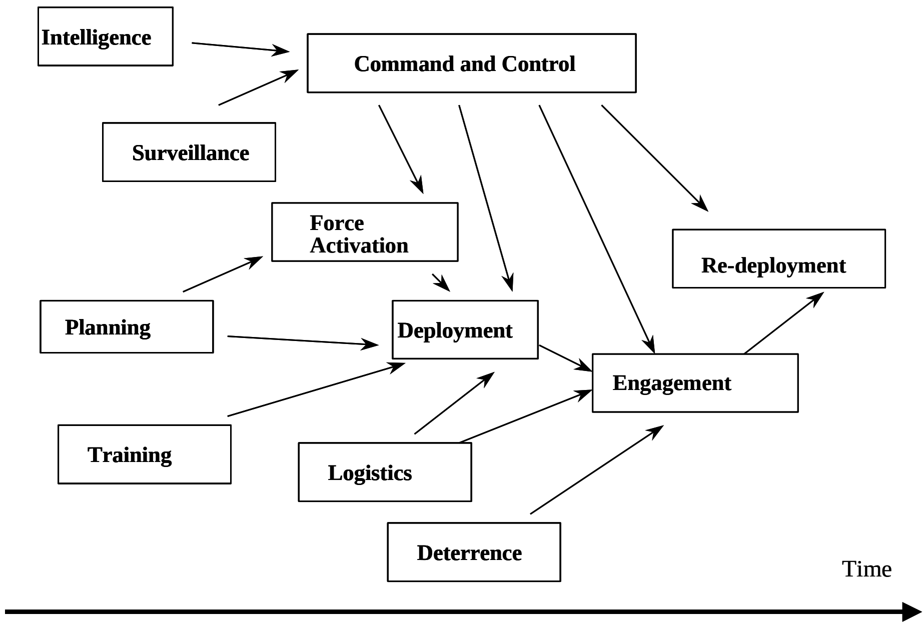

Figure 5: Military Processes and Functions.

Deterrence is not a direct phase of potential crisis. It is a very important function in all situations to create a perception in view of the opponent or warring parties that a conflict is not in their interest. Deterrence has many aspects; it has to be seen at all levels, at all phases and for all conflict types. An important contribution to create this perception is the demonstrated knowledge about the actions, the situation, the status and the capability of the opposing forces and, if possible, the intention. This can be accomplished through the use and demonstration of modelling and simulation of the respective situation. The effective reconnaissance and surveillance at all times and the careful demonstration provide also an invaluable contribution to the overall deterrence function. If deterrence works, crises can be resolved early; the extremely expensive deployment and employment of combat troops can be avoided. If deterrence fails, crises can lead to catastrophic situations with many casualties.

Utility of modelling in the functions and phases				
Functions and Phases	Free Form Games	Interactive Simulations	Closed Simulations	Analytical Models
Training	Limited	Very High (CAX)		
Planning		High	Very High	High
Force Activation		Limited	High	Very High
Command and Control			High	Very High
Surveillance			Limited	High
Intelligence				Limited
Logistics			Limited	High
Deployment			High	Very High
Operations			Limited	High
Re-deployment			High	Very High
Deterrence	Limited	Very High	High	High

Planning Situations

Planning and definition of situations, which can serve as basis for testing the effectiveness of structures, systems, plans, and concepts of operation, are closely linked. If such situations cover a set of future most likely possibilities, it is save to assume that structures and concepts based on these situations give robust solutions. From an analysis perspective, given or planned solutions should be tested against these planning situations seen as benchmarks.

From the analysis of crises a number of common factors that are relevant to generic planning situations emerge. These basic components of military planning identify the common questions confronting planners in every situation. From these common factors detailed checklists of generic planning tasks can be identified that also reflect the political and strategic guidance of generic planning.

The challenge, which exists for military planners today, is the uncertainty of potential scenarios on the background of the new space of missions for NATO and nations (see Figure 6). The number of scenarios, which have to be considered, is increasing with the time horizon for planning. At any present time, usually only one or two real life operations are of importance. For short-term planning, the given forces have to be employed and analysed in relatively well-known situations. For long-term planning, many planning situations with increasing uncertainty have to be considered and analysed. In general, the set of scenarios and planning situations should be as consistent as possible.

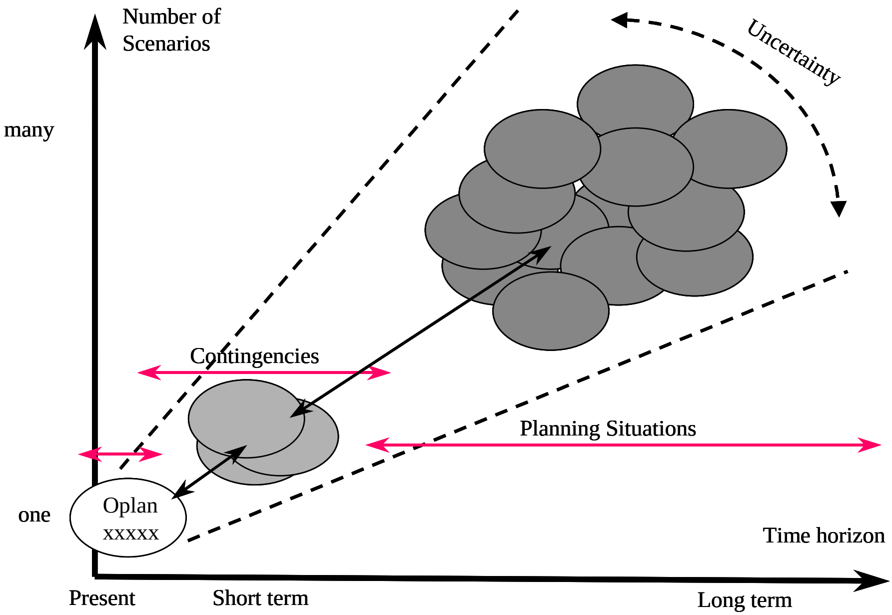

Figure 6: Uncertainty of Scenarios.

Decision Cycle

A typical cycle of actions takes place in any Command and Control (C2) process. This so-called decision cycle or Observe, Orient, Decide, Act (OODA) loop is established more or less at all levels, within all forces and is taught in most military academies (see Figure 7). It can be interpreted as an intelligent system, as defined in Figure 1.

The starting point is the definition of the desired objective. Then the status of own and opposing forces and the environmental circumstances in which they might have to operate need to be established. The potential of the forces can be compared using simulations. Environmental conditions, scenarios and planning situations can be changed in the simulation. Operational options can be developed from the results of the comparisons. The likely effects of adoption of the options can be assessed, using simulations. The best option can be selected as a basis for decision-making and further planning.

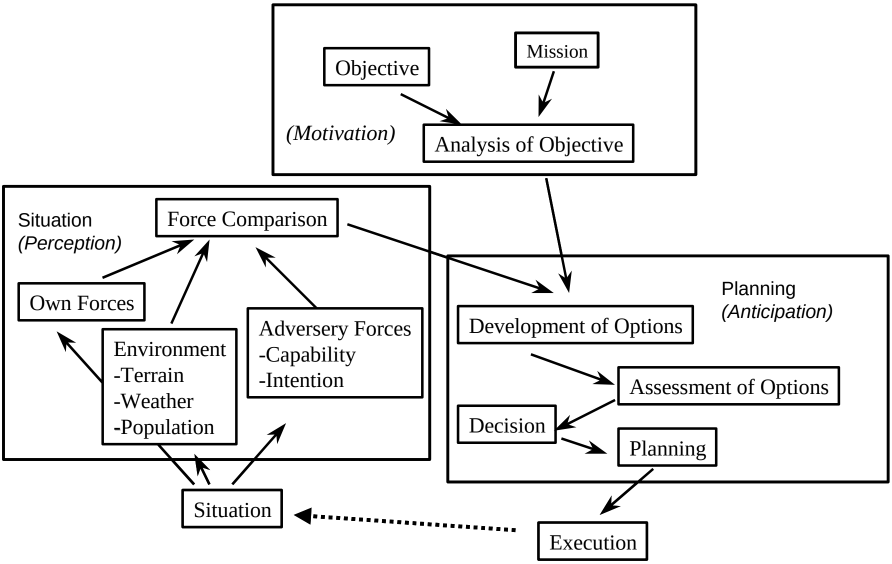

Figure 7: Decision Cycle.

The procedural elements of this classical decision process are in general:

- Situation Assessment
- Objectives
- Strategies/Options for Actions/Decisions
- Detailed Planning
- Implementation and Control.

Any military staff or crisis management teams carry out the five elements of this process repetitively during the operation. The process always begins with situation assessment. It encompasses all the activities concerned with finding out and describing what is going on; understanding the motivation of the principal actors; establishing the basic causes of the situation and the relevant drivers of the process; updating the assessments; and disseminating the assessment to other people if required.

In order to illustrate the problems of decision-making in a complex military crisis situation, three fundamental dimensions are to be considered:

- The time available to make a decision,
- The complexity of the decision, and
- The uncertainty of the available information about the situation.

These three factors reflect the risk or opportunity inherent in a military situation. The more complex a situation, the less time available, and the greater the uncertainty of the available information, the greater the present risk (and opportunities). One end of the spectrum or decision space represents the worst situation for any decision maker – almost no time available, an enormously complex problem and considerable uncertainty about the situation. When these conditions exist, the decision maker or military commander has no other choice than to use the so called *best professional judgment* to match the battle space situation to some class of well-understood military situations and act accordingly. In any case the best professional judgment and a wise commander will try to take short-term actions designed to create more time and/or more information and in this way relocate the problem to a better portion of the space. The opposite end of the decision space, defined as ample decision time available, limited complexity, and low uncertainty, provides the ideal situation for decomposition of the problem and the development of optimal military plans. Many innovations in command and control systems are designed to move the situations facing the commanders toward this region. An important contribution is provided using advanced modelling and simulation technologies.

Model Utility for decision cycle activities					
		Free Form Games	Interactive Simulation	Closed Simulation	Analytical Model
Motivation	Analyses of Objectives	x			x
Situation Perception	Environment				x
	Own Forces		x	X	x
	Enemy Forces		x	X	x
	Force Comparison		x	X	x
Anticipation and Planning	Creation of Options	x			x
	Analyses of Options		Limited	X	x
	Decision				x
	Detailed Planning		Testing	Testing	x
	Control				x

Conclusions

Military Operations Research, as well as Modelling and Simulation, has long tradition. More than 2000 years ago Sun Tsu, the oldest known philosopher of war, wrote:[7] "To win without fighting is best." He also wrote:

> "The rules of the military are five: measurement, assessment, calculation, comparison, and victory. The ground gives rise to measurements, measurements give rise to assessments, assessments give rise to calculations, calculations give rise to comparisons, comparisons give rise to victories."

Both statements indicate the requirement for the military planner and decision-maker to use methodologies, such as modelling and simulations, for the best creation of solutions. General Eisenhower wrote:[8]

> "The Army must have civilian assistance in military planning as well as for the production of weapons. Effective long-range military planning can be done only in the light of predicted developments in science and technology. As further scientific achievements accelerate the tempo and expand the area of our operations, this inter-relationship will become of even greater importance. In the past, we have often deprived ourselves of vital help by limiting our use of scientific and technological resources to contracts for equipment. More often than not we can find much of the talent we need for comprehensive planning in industry and the universities."

Many others give evidence that the rational, logical, quantitative consideration of facts results in better understanding of the phenomena of war and in improved operations and strategies.

In the past, defence planning was based, sometimes explicitly, on the view that the future would be much like the recent past. This perspective on the defence planning process can be seen as a *pipeline.* Research and development are poured into one end and eventually the results appear as fully deployed systems at the other end. A common perception has been that the value of research and development accrues only if and when fully deployed systems materialise.

On the other hand, research and development creates value in and of themselves before any production or deployment. A developed and demonstrated potential to produce or deploy certain systems is a product in its own right and can provide options and hedges against an unknown future and mitigate the consequences of surprise. Also, the potential of future deployment can influence possible adversary behaviour. In effect, research and development cast a *long shadow* forward, its influence felt long before any deployment. In addition, there is a growing difference between what is technologically available and technologies actually embodied or required in deployed force structures.

In any case, these effects should be of interest for future defence planning and detailed quantitative analysis utilising operations research methodology, modelling and simulation.

The increased emphasis on the strategies to deal with the greater uncertainty of the future and the need for projecting military potential lead to concepts, which could be characterised as virtual deployment of forces and artificial experience. Potential adversaries can perceive the virtual deployment as capability long before any actual deployment takes place. It could include various stages of development, demonstration, prototyping and limited production. In the future, military competition may be characterised more by development and by maintenance of such virtual deployed options, than by deployed real systems. The virtual deployment, in close relation to the growing gap between civil technology and deployed military technology, will magnify an already existing trend, the reliance on and the need for artificial experience, modelling and simulation.

Increased environmental concerns, smaller budgets and resource constraints have already motivated great interest in simulation techniques and capabilities. The interactions of new technologies embedded in future forces and of their counter- and counter-counter-measures will not be well understood. Virtually deployments cannot be actually tested on the field. High fidelity simulation and training techniques used not only for deployed systems but to assess the interoperability of potential developments and virtual deployments will increasingly be the tools for military planning and education.

Bibliography

David S. Alberts, John J. Garstka, Richard E. Hayes, and David A. Signori, *Understanding Information Age Warfare* (Washington, DC: CCRP, 2001), <http://www.dodccrp.org/publicat.htm> (19 December 2003).

John R. Boyd, *Patterns of Conflict* (1977), <www.belisarius.com> (19 December 2003).

Alfred Büchel, *Systems Engineering* (Moderne Industrie, Management Enzyklopädie, 1971).

James R. Emshoff and Roger L. Sisson, *Design and Use of Computer Simulation Models* (New York, NY: Macmillan Company, 1970).

Stanley A. Erickson, Jr., "C3 and Combat Simulation - A Survey," in *Systems Analysis and Modeling in Defense: Development, Trends and Issues*, ed. Reiner K. Huber (Plenum Pr, 1984).

Reiner K. Huber, *Systemtechnik und Waffensystemplanung Grundlagen, Ansatz, Probleme* (Oldenburg: Waffensystemplanung, 1977): 6-9.

Wayne P. Hughes, Jr., ed., *Military Modeling* (Military Operations Research Society, 1984).

George A. Joulwan, "SHAPE and IFOR: Adapting to the Needs of Tomorrow," *NATO Review* 44, 2 (1996).

Klaus Niemeyer, *Systemanalyse* (Moderne Industrie, Management Enzyklopädie, 1971).

Otto Reidelhuber, "Modelling of Tactical Decision Processes for Division Level Combat Simulations," in *Systems Analysis and Modeling in Defense: Development, Trends and Issues*, ed. Reiner K. Huber (Plenum Pr, 1984).

Robert F. Robinson, "Methods for Analyzing the Contributions of C3 to Military Force Capabilities," in *Systems Analysis and Modeling in Defense: Development, Trends and Issues*, ed. Reiner K. Huber (Plenum Pr, 1984).

Computer Generated Forces Technology (RTA-NATO, AC/243 (LTSS)TR/48, 1998).

Bernard P. Zeigler, *Multifacetted Modelling and Discrete Event Simulation* (Academic Press, 1984).

Notes:

1 *NATO Modelling and Simulation Master Plan* (NATO AC/323-WP/04, NATO-RTA, 1998).

2 Philip M. Morse and George E. Kimball, *Methods of Operations Research* (New York: John Wiley & Sons, 1958).

3 See definitions in *NATO Modelling and Simulation Master Plan*.

4 Herbert Stachowiak, *Allgemeine Modelltheorie* (Springer, 1973).

5 Stachowiak, *Allgemeine Modelltheorie*.

[6] Klaus Niemeyer, *A Contribution to the Typology of Games*, in *Operational Gaming*, ed. Ingolf Stahl (Pergamon Press, 1983), 41-52.

[7] SunTsu, *The Art of War*, translated by Thomas Cleary (Boston: Shambhala, 1988).

[8] General Eisenhower, Internal Memorandum (Washington: War Department, Office of the Chief of Staff, 1946).

KLAUS NIEMEYER was born in Bremen, Germany, in 1941. He left Gymnasium in 1958 and studied at the Physikalisch-Technische Lehranstalt in Lübeck and Hamburg, graduating as Diplom-Ingenieur in Technical Physics in 1963. During this period he worked also in industry, primarily with Entwicklungsring Süd, in the computing field. On graduation Mr. Niemeyer moved to Boelkow Entwicklungen KG in Ottobrunn, near Munich, where he worked as system analyst in a team of U.S. and German scientists that initiated the German Operations Research activities for the German Ministry of Defence.

Mr. Niemeyer has had a long and distinguished career in Military Operations Research, Simulation and Computer Applications. In 1965, he joined the Industrieanlagen Betriebsgesellschaft mbH (IABG) in Ottobrunn with other German members of the above-mentioned team, and helped in establishing the Systems Analysis area at IABG. In 1966, he was assigned to US/GE advanced V/STOL-fighter assessment at the Wright Patterson Airforce Base in Ohio. As Project Leader he evaluated and analysed airborne and airbase systems.

In 1969 Mr. Niemeyer was appointed head of a group working on optimal air force structures. In this role he developed and operated the first German computer-assisted exercise in 1970. This formed the basis for establishment of the IABG Wargaming Centre, of which Mr Niemeyer was appointed Chief in 1972. In this position, Mr Niemeyer initiated development of several concepts, models, approaches and solutions to assessment and evaluation of force structures, and helped initiate international programmes such as the US/German European Conflict Analysis Program (ECAP), and the Joint Simulation (JOSIM) Project. He has been responsible for many national and international studies in the areas of weapon system assessments, air and army structures, command and control, force effectiveness comparisons, arms control, conflict research, operational support, long-term defence planning, logistics planning, war gaming, exercises, and information systems support.

Mr Niemeyer became Chief Scientist and Head of the Operations Research Division at the SHAPE Technical Centre (now NATO Consultation, Command and Control Agency) in May 1992. In this position he was the principal advisor on scientific matters and military operations analyses that affect SHAPE and Allied Command Europe. Among other projects the Allied Deployment and Movement System (ADAMS), the methodology for the Defence Requirements Review (DRR) and the High Level Exercises have been developed in his area of responsibility. Mr. Niemeyer initiated and co-chaired the Steering Group on Modelling and Simulation and represented his organisation in several other panels and committees within NATO. Mr. Niemeyer retired from NATO in April 99 and now he works as a consultant. *E-mail*: niemeyer.oa@t-online.de.