Duels of Systems and Forces

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This paper begins with a brief summary of the vital changes in warfare during the last decades as seen by the author: Mass armies are no longer common tools for warfare. The "big" war has become unusual, while limited (and controlled) use of military forces for political purpose still is in use. However the ability to maneuver and fight with weapons still remains a basic military skill and modeling of combat remains important for understanding war. A formulation of a basic problem for single weapon systems is made and the effects of technology development are discussed in that context. Further comments are given on problems in information processing in modern weapons and in Command, Control, Communication and Intelligence, where the technological changes are expected to be revolutionary. A short comment is also given on transforming single weapons data to force characteristics, which is important for connecting analyses on low levels with those on high levels. The author also gives some comments on Operations Other Than War and Asymmetric War – which are new challenges for military analysts as well as officers. Finally a critique is given on the state of the art in military modeling.

1 Introduction

This paper focuses on duels of systems and forces in war and will give some thoughts on technology changes and the use of quantitative modeling in that context. These thoughts are based on my experience from more than thirty years as a military analyst (operations research) at the Swedish Defence Research Agency.

The central part of my paper gives some different background views to help understand the present development in warfare. The technological change is of course a fascinating and terrifying subject, which also will be central in this presentation. However, it is also vital to mention the development of attitudes to violence, which gives a framework for warfare activities.

2 Characteristics in Present and Future Warfare

Before going into the duels of systems and forces, it will be useful to mention some characteristics in present and future warfare. The first characteristic is that we have been able to avoid all-out-war with mass armies during the last half century.

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There may be several reasons for that. One can be the technological development of weapons and war systems that have made all-out-war with mass armies out of date. A phrase that characterizes the consequences of technological development during recent years and will be used in coming years is “Revolution in Military Affairs” – RMA. I will come back to that concept.

However, there is another explanation to why the time of mass armies and all-out-war is over and that is “Revolution in Attitudes to the Military” – RAM. That concept is not as well known as RMA, but I think it is even more valid. The concept RAM is from a war historian and philosopher – Jeremy Black.

The change in attitudes to the military has many causes. Underlying all these causes is the change in society due to industrial and technological revolutions. Risk of violent death for people in ordinary civilian life has been substantially reduced and many people have a rather decent living. Large casualties among ones own forces are no longer accepted. There also exists a high moral uneasiness in causing collateral damage and even casualties among enemy forces. In parallel to that, most societies have abandoned military triumphalism – a victory may not be worth the prize. A reluctance to serve in the military has in many societies contributed to a radical decrease in number of personnel serving in military forces.

The media is very critical toward war and the CNN effect is important. There is also a heavier emphasis on how to get fast political results out of military activities. And the political result is less than ever a simple function of destroying the enemy.

However, even if there has been no all-out-war in the last half century, there have been wars! These could be characterized as low-level conflicts – asymmetric wars between conventional forces and guerillas and terrorists and some low technology wars – and there have even been some conventional wars on medium levels. Even if the words low and medium conflicts are used, those wars have caused much suffering. And it is difficult to see an end to conflicts like these.

The nuclear threat has been, and will be, a continuous heavy factor in many security policy considerations.

My conclusion is that it is still meaningful to try to understand warfare in all its shapes.

3 A Basic Duel

In all above conflicts the basic phenomena are duels between lethal weapons. The development of non-lethal weapons during the last decades remains only a marginal phenomenon and mostly used for riot control or special circumstances in war operations. Before elaborating on the technological changes I will define what I think is a basic duel between lethal weapons.

Fundamental in many combat situations is a weapon firing at a target that has ability to hide or to move out of the dangerous area. The target tries to hide as long as possible and will make the shortest possible exposure. The weapons operator will then make the time for aiming as short as possible in order to deliver a shot with enough precision to hit the target.

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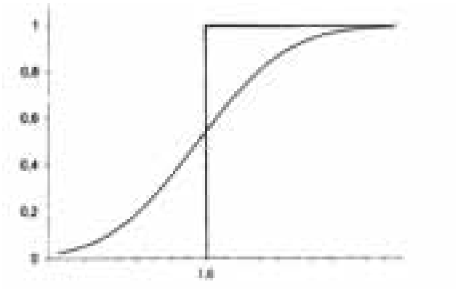

Figure 1. A basic duel.

A single weapon aiming at a target:

t_d Time to aim and deliver at shot
t_e Target exposure time

Deterministic:

$$P(\text{hit}) = 1 \text{ if } t_e/t_d > 1{,}0$$

$$P(\text{hit}) = 0 \text{ if } t_e/t_d < 1{,}0$$

Or stochastic:

$$P(\text{hit}) = F(t_e, t_d)$$

Even if this is a basic situation in military activities, it is not the most frequent. Most of the time in military activities in combat is spent *maneuvering* weapons to achieve favorable positions for such duels. Most military activities are preparations for such duels.

A characteristic of a duel is a struggle in time between two opponents. The value of better performance in t_d must be related to data in t_e and vice versa. There is no meaning in good performance in t_d if the target is even better in t_e. Many activities are aimed at being in the right place at the right time and achieving a time advantage. A simple weapon can be efficient against a more advanced weapon by firing some hasty shots and scooting out of the opponents lethal area before he is able to return the fire – that tactic is called shoot and scoot.

Another characteristic is that the result is stochastic. The actors are human and cannot be trained to deterministic behavior. Even if it often is necessary or convenient to consider duels deterministically, as a part of a more complicated analysis, one must remember that the end result would be stochastic.

Notice that neither t_d nor t_e are directly represented in the Lanchester equation that was mentioned in the previous paper. However, the phenomena are there in indirect ways.

A very important characteristic is that the duel concerns information processing. An example is a situation where one weapon outranges an enemy and is able to deliver a shot without the enemy being able to shoot back. Information processing is vital to be able to outrange an enemy. One modern way to do this is to use guided weapons, which are dependent on information processing.

4 Technological Change

Information processing is a vital part of most military activities. Information technology is also the field where the projected advances are likely to be in a true sense revolutionary. There will also be advances in many other fields, but I cite also a conservative judgement. O'Hanlon states that information technology is the only aera where the advances will be truly revolutionary. However, in that field there may be technological advances that have not yet been implemented by military applications. (Krepinevich)

Here it seems suitable to elaborate a little on the military decision-making and management of operations. To give a more complete picture, I will introduce some of the words used in the military organizations in that field and choose to do that by explaining a stream of acronyms – CCCCIIWS!

The first C stands for command, which means that orders and instructions should be delivered to their destinations in time.

The second C stands for control, which means feedback for the commanders being aware of the situation in their unit of command. Much effort is devoted to give the commanders an *enhanced situational awareness*. The means are better information processing to reduce delays and to find better ways of presenting information for commanders and staff officers.

Before the information technology era the usual acronym for management in military activities was Command and Control. Sometimes that acronym or others are still used.

The third C stands for communication and communications systems moving information between commanders and staffs. Modern communications systems are developed towards *networking*, which means that information is transmitted also sideways and not only up and down in a hierarchy as in the old military way. A modern acronym in the military world is Network Centric Warfare (NCW). An important problem is how staff officers and others will be able to avoid being blocked by too much unnecessary information. There is a need for a flexible way to evaluate information and to let through only what is wanted. The amount of information that can be carried by a single radio channel is however limited. This and other limitations highlight the importance of developing software capable of information processing close to the source of information.

The fourth C stands for *computers*, which are more and more introduced in

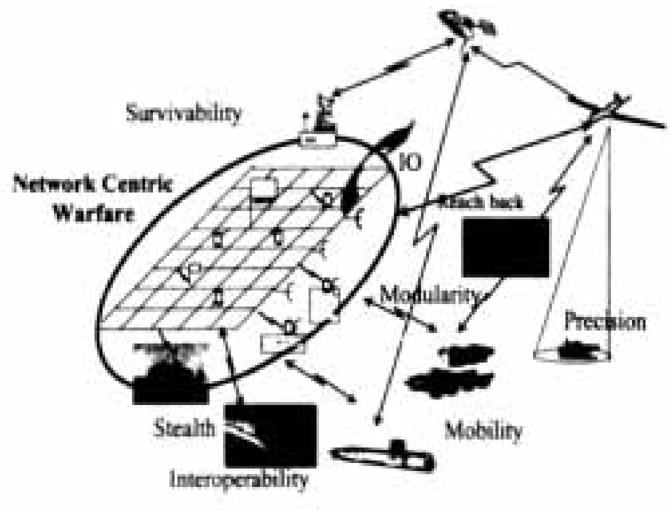

Figure 2.
Network Centric Warfare.

military management and for a wide range of missions. The trend of remarkable progress in computer technology shows no immediate signs of slowing down. The benefits of improved computing speed will be devices such as handheld computers and wrist telephones. These types of technology will continue to tie together the future battlefield and make it possible to equip many more soldiers with high performance computational gear. The capability could be used in scout teams to call in long-range firepower. In addition, automatic target recognition will make autonomous munitions that are resilient to countermeasures. Automatic target recognition will also permit substantially increased use of unmanned flying platforms (UAVs).

The first I stands for *intelligence* or information, which it is all about. The IW stands for *information warfare*. The definition of IW is wide and covers for instance electronic jamming, camouflage and also deception. It is a field where much effort is already spent. The technology part in this field started with electronic warfare that has been present from the beginning of electronic communication. It has expanded much during the last decades and will continue to expand in the future. Information operations may even be a new way of conducting war.

Characteristic in information warfare are the very complex duels that may take place and the long chain of counter-counter-counter loops. A first step may be a simple camouflage against a sensor. Then the sensors may get information processing that will see through that simple camouflage. The next step may then be better camouflage or a tactical change that reduces the exposure.

I will come back to IW after some word on sensors. Further on there will be a presentation on information warfare in the following paper of this volume.

S stands for sensors and I gave an introduction to that in the beginning of this paper. Sensors are vital for giving information to guided weapons, for aiding operators and conventional gunners, but also getting tactical information that is vital to maneuvering on the many levels of hierarchy that exist in military organizations. In connection with sensors there will be more and more automatic information processing, for instance for target recognition. Further, miniaturization of electronic components is improving the performance data of radar on satellites, aircraft, unmanned flying platforms, missiles and guided munitions.

A modern joint surveillance and target attack radar system (JSTARS) aircraft can form detailed images of the ground while simultaneously scanning for mobile targets in a search mode. Among the most important areas of radar development are attempts to penetrate below the forest canopy and to a degree certain types of soil. Other types – bistatic and multifrequence radars – will be able to challenge stealth technology.

Infrared sensors will also be improved with further increases in detection range. Improved information processing will also be able to detect weak signals passing through light rain. An infrared-system under development (LANTIRN) will allow use from aircraft in flight-levels more than 10 000 meters. Other systems may be able to pick up heat signals from snipers camouflaged from visual observation.

Night-vision light-imaging detectors for infantrymen work over a range of one to two kilometers, meaning that soldiers now can see as far as their weapons can accurately fire. More advanced devices use infrared detectors, which will give

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information even in perfectly dark conditions.

In brief, advances in sensor technology have been huge and development will continue. However, two main principles constrain their potential. They must all function according to the laws of physics. And the everlasting information war – for every new sensor developed, countervailing efforts will be made to defeat it.

Radar and radio waves can penetrate clouds and rain and to a lesser extent foliage and soil. But they cannot physically penetrate deeply into soil or water. Nor can they reach inside sealed metal containers. These limitations open up possibilities for an adversary to develop countermeasures that explore those limitations.

Another fundamental constraint on radar is that it is active and energy emitting, which makes it susceptible to countermeasures. A counter-counter action is to minimize the use of radar. For example, highly directional wide-bandwidth radar beams minimize the chances of detection. And then the counter-counter-counter action is detection networks with even more advanced information processing.

A target that possesses a radar receiver will generally notice that it is being examined before weapons can be launched against it. It will then have the opportunity to take defensive actions: shooting back on the enemy, turning on radar jammers or simply ducking for cover. One possible result is that large aircraft like JSTARS will fly further and further away from the battlefield in order to stay out of range of antiair missiles. However, beyond a certain distance, the curvature of the earth will set the limit.

Military forces that are maneuvering on the ground, flying, or sailing will give a high technology adversary important advantages in a symmetric warfare. The advantages will be less notable in other combat settings.

5 Future Warfare Due to Technological Change

What do the trends in key military technologies portend for future warfare? And what about the validity of the most common hypothesis that a revolution in military affairs (RMA) is on the way?

The official opinions in the United States and many other countries reflect grandiose and ambitious interpretations of what a revolution in military affairs should entail. There are information systems, sensors, new weapons concepts, much lighter and more deployable military vehicles, missile defenses and other capabilities. They also include the terms dominant maneuver, precision engagement, full dimension protection and focused logistics.

However, some fields show few signs of major breakthroughs. The speed and weight of most means of transportation are not likely to change drastically. Neither are battlefield-armored vehicles likely to improve drastically. The aspirations for dominant maneuver and focused logistics may also be too optimistic.

A field with great expectations that O'Hanlon confirms is autonomous and homing munitions, which will improve in absolute terms over the next two decades. Whether they improve as dramatically in relative terms remains to be seen. Enemies may learn to reduce the effectiveness of these munitions substan-

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tially through the use of sophisticated countermeasures. The potential of these weapons is considerable but it will be realized depending on the opponent and other circumstances. O'Hanlon says:

> […] the popular notation of information dominance simply goes too far. It is one thing to determine that a silicon-based modernization is the best way to modernize U.S. defense capabilities. It is another to claim that warfare will radically transform in the years ahead. The former conclusion seems a sober analytical judgment. The latter is a leap of faith upon which a sober scientific survey casts considerable doubt.

The following characteristics are also from O'Hanlon:

Likely technological accomplishments between 2000 and 2020:

- Computers – there will be a tenfold increase in capacity.
- Networking of data between various platforms will be operative.
- Autonomous munitions and unmanned sensors will be increasingly effective.
- Satellite imagery will become much more widely available.
- Long range radar sensors will be able to detect large vehicles under forest covers.

Challenges likely to remain elusive through 2020:

- Aircraft, ground vehicles and ships will not become radically faster or lighter.
- The large oceans will not become "transparent" to any sensor.
- Soldiers and small arms in urban environment and to some extent also in forests will be very difficult to track from long distances.
- Soldiers operating in small groups will often be able to get the first shots against any intervening forces.
- Sensors and munitions will not improve enough to hold targets in buildings and underground at risk.
- Things transported inside well-sealed metal boxes will not be detectable by long range sensors.

To evaluate the development and to reach and further elaborate answers like the above, it is important to systematically survey the potential of a wide range of defense technologies and systems. For developing military applications there is a need for analyses, experiments and evaluations. There will be a need for military analysis from many aspects.

6 Diffuse Conflicts

So far analysis of duels of systems in combat have been the common subject. And the technological development has been commented on. The capacity to perform in combat is still the ultimate reason for military forces. However, most missions that modern military forces conduct are in Operations Other Than War (the military acronym is OOTW). Further, most wars have been *asymmetric* in some aspect. And also most other conflicts have changed to a more diffuse pattern,

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where the connection between military means and political goals are much more complex than before! Operations other than war can be seen as the extreme opposite to war in this context. So I start there.

Operations other than war are mainly: peace operations and aid to the civilian authorities in catastrophes of some kind. Peace operations could be defined as (D. Davis 1998):

- Peace Making primarily conducted by the diplomatic community – the negotiation, mediation, treaty and accord building that remains central to all Peace operations.
- Peace Building primarily conducted by governmental agencies, non-governmental organizations and the UN – the attempt to address the root causes and exacerbating circumstances that hinder the Peace Making effort. These usually include Human Rights functions, humanitarian Relief, Refugee Activities, Good Governance, Infrastructure, Economics and Demilitarization.
- Peace Support primarily conducted by military organizations – The use of Command and Control, Force, Security, Presence, Observation, Liaison and Logistics to provide the space necessary for Peace Making and Peace Building to occur. Often it is convenient to use the words *Peace Enforcement and Peace Keeping*.

When military organizations are used for operations other than war the main effort is often to provide mobile logistics with an efficient management. I will not go further into that complex but will instead concentrate on duels with weapons and forces in Peace Support Operations and diffuse conflicts.

The use of weapons in operations other than war can be characterized by:

- An early step is to establish conditions allowing for *negotiations* from a position of strength.
- Military force should then *assist* in the resolution of the conflict and any attempts to alter the conditions.
- As the conflict de-escalates, the military role decreases.
- Troops require conventional combat skill tempered by stringent *rules of engagement*.
- The commanders need also effective use of intelligence, civic action and psychological operations.

Notice the rank order of these characterizations. Military means are used to establish conditions for *negotiations*. Notice also that duels between weapons and forces are much more restricted in this context than in war. The *rules of engagement* are very important. In general the military must exhibit a much higher regard for those rules than in conventional war situations. That implies that technological features of weapons could become secondary. Further: use of weapons is more and more controlled from higher levels in the chain of command due to their responsibility to act with diplomacy in most situations. In peace keeping operations common soldiers may use weapons only in self-defense and to save lives in evident cases.

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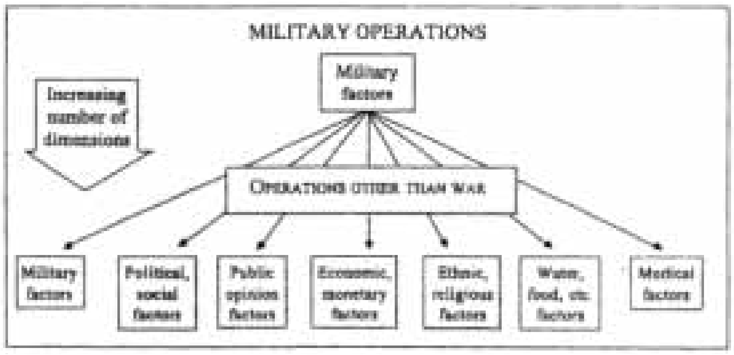

Figure 3. Multiple dimensions of conflict.

In brief: military operations other than war and related humanitarian activities take place in environments involving the interplay of many different types of social factors and processes (Woodcock), see Fig. 3.

I would like to add that these comments are valid also for many of the diffuse conflicts that we see at present and probably will see in the future.

The Vietnam War is a good example of warfare where the old rules for achieving a victory were not valid. That war was asymmetric in many ways and so will other wars between two parties develop, where one combatant use high technology means and the other combatant use guerilla or terror means.

In future diffuse conflicts the range of problems might still be expanding. Highly complicated behaviors can occur. Even well intentioned and well-thought actions may have very negative unintended consequences. Providing food and water to starving people can be interpreted as giving significant advantages to adversaries. Events can be stage-managed for the benefit of international media in order to change the perception of apparent realities and influence opinion. Under such circumstances it is evident that the planning and execution of many operations should be based on analyses that take into account the complexity of the human, societal and political environment within which they take place.

Empirical evidence indicates that quantitative analysis of operations other than war and the “diffused new wars” are less frequent than in analyses of conventional war. There are some good reasons for that but also some not so good.

To support this kind of operations there is a need for systematic studies of behavioral patterns that can be identified and measured. Data from which those patterns can be identified are the historical, social and other records of interstate conflicts. Here the difficulties have been rising. The relevant specialists often do not dwell on trying to pinpoint similarities and differences among a number of different events. There is a trend to direct more attention to the uniqueness of the particular event under examination rather than its similarities to other events. Most conflict data sets provide extensive detail on a selected number of different types of conflict episodes, rather than a brief description of a broader set of con-

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flicts. However there are some schools of quantitative researchers that are closer to meeting some of these needs.

My comment on these thoughts, which are from Barr and Sherill (1996), is that we must realize that operations research studies in these matters are still in an early stage, compared with mathematical studies on conventional war, that now have more than fifty years of development and experience. An observation, however, suggests that resistance against quantitative analysis is stronger here than in the more conventional war analyses. And that resistance is quite strong even in the conventional military field as I will come back to.

I cannot resist the temptation to end this part with a formulation by Dr. Karen Toombs Parsons:

> Most analysts in the policy community [...] rely on more traditional qualitative research techniques. Many have an almost *theological aversion* to trying code information about social/relevant phenomena. They proudly proclaim that they do real analysis, not "crunch numbers".

7 Levels in Combat Dueling

We now continue to discuss duels between systems and forces and explore some aspects of modeling such duels.

To evaluate the implications and the possibilities of technological changes, the analyses must be conducted in different levels of resolution. In military analyses the natural breakdown in levels is:
- strategic,
- operational,
- tactical,
- military technical.

At each level models are needed for alternative representations of dueling, to reflect different facets of a problem or to serve different purposes.

On a military technical level there are one-on-one models. They are of course a simplified description for pure weapons analysis. Such duels can be symmetric – for instance tank versus tank – or asymmetric – tank versus anti-tank missiles. Such a model will not permit any analysis of interaction between friendly systems and units or for analyzing management of military forces in combat. To allow this the models must represent *few-on-few* or *many-on-many*, which is another class of models.

Even if modern computers can handle enormous amounts of information it will be too impractical with simulations of type many-on-many when large amounts of weapons and equipment must be analyzed. Then it could be useful with a model of type *force-on-force*. In such a model clusters of weapons and equipment are combined and represented as units with a few characteristics. Thereby the volume of descriptions of the total mass to be modeled can be reduced compared with what has to be done in a many-on-many model. It appears convenient but another problem arises and that is to make the descriptions in the force-on-force model *compatible* with results from simulation models. Here is a field for interesting mathematical applications, which I will elaborate on later.

Then you have a choice. When you are analyzing a problem on high or medium level a choice has to be made: to use a low resolution model with approximations or a high resolution model that explicitly gets you down to a lower level. This deserves of course a lengthier discussion than what is possible to give here. The principal reasons are as follows (P Davis):

There is a need for low resolution modeling on a high level for:
– comprehension and understanding of interaction between forces (seeing the forest rather than the trees),
– analysis for structure decisions and strategic or operational level decisions,
– low cost and rapid analysis,
– making use of low resolution knowledge and data (frictions of war!).

There is a need for high-resolution models on a low level for:
– understanding tactical and technological phenomena,
– representing systems knowledge and simulating reality,
– calibrating or informing lower-resolution models,

Notice the complication that important *data* on "frictions of war" mostly are available at low resolution on a high level. And a fundamental *understanding* of tactical or technological phenomena in war is mostly connected with high-resolution analysis on a low level.

To conduct analyses on different levels, the most common way is to use alternative models for each level. Often those models and databases are inconsistent. At best such a collection of models is combined with "good engineering practice" which means there are some procedures for using the more detailed models to calibrate selected input parameters in the lower resolution models.

However, during the 1990s there has been a development of methods for systematic and consistent variable resolution modeling with consistent mathematics. Lanchester differential equations are central in that development. In general they create an opportunity to reach a mathematically consistent way of transmitting information from low-level models (simulation models) to higher-level models.

Even with Lanchester models the amounts of information will be impractical when large amounts of weapons and equipment shall be analyzed. However, the Lanchester formulation gives the opportunity to model *force-on-force*. In such a model clusters of weapons and equipment are combined and represented as units with a few characteristics.

The mathematics used is eigenvalue solutions to matrices. Here I give a general outline of the mathematics. Jaiswal gives a complete description. The basic Lanchester formulation is:

$$\frac{\mathrm{d}B_i}{\mathrm{d}t} = -\sum_{j=1}^{m} \beta_{ij} R_j \qquad i = 1, 2, \ldots n,$$

$$\frac{\mathrm{d}R_j}{\mathrm{d}t} = -\sum_{i=1}^{n} \gamma_{ij} B_i \qquad j = 1, 2, \ldots m,$$

where β_{ij} is the number of i-th type of Blue force weapons destroyed by one unit of allocated j-th type of Red force weapons per unit time and analogously for γ_{ij}.

With some good assumptions it is possible to derive eigenvalues to these matrices and reduce the voluminous differential equations to:

$$\frac{\mathrm{d}V_b}{\mathrm{d}t} = -C_r V_r \ ,$$

$$\frac{\mathrm{d}V_r}{\mathrm{d}t} = -C_b V_b \ ,$$

where C_r is the aggregated attrition rate coefficient for Red force and analogously for C_b.

The units of V_r and V_b are often chosen according to the ordinary military organization – i.e., company or division. That means a single combat value is used for a company or a division.

The method hinted at above will require theoretical efforts to develop good approximations to separate phenomena occurring on different levels. One will then recognize that relationships often are complex and not intuitive. Davis thinks that there is a great potential for developing powerful variable resolution models, but a great deal of work has yet to be done, if we are to achieve that.

I agree with Davis and will add that with good models on high levels that are consistent with data on lower levels, it might be possible to develop better analyses on problems like force structuring and operational planning. Aspin and Huber have given some examples. The mathematics they use in their models is very simple but they are dependent on aggregated data from lower levels.

8 Mathematics in Modeling Duels

In previous parts I have given some indications of mathematics used in analyses of duels of systems and forces. I will also give an overview of mathematical techniques that can be found in such analyses.

Let us start with *probability* modeling as given by my elementary introductory example. A more realistic but still generic case is a weapon system for defense against missile attack, for instance on a ship. That weapon system is characterized by its probability of acquiring for a specific target, acquisition time and lethality time, that is the time to achieve a kill on an attacking missile once it is acquired.

These parameters are design features. Trade-offs between these weapons characteristics exist. The simple probalistic model may provide insight in deciding the desirable parameter configuration. That kind of model can also be used to understand the defensive threat experienced by the attacker.

Such methods are used in a wide range of analyses – from infantry weapons to nuclear. There are of course many ways to conduct those analyses and I will not go further into that field. My example above is from Almeida.

My basic example indicates that time delay in information processing can be important to calculate. It is thus evident that *queuing* models can be useful.

One example can be a forward air control officer that shall assign combat air fighters to missions, taking into account the aircrafts armament, the requirements to get effects on a certain target and other factors. By running such a model under different scenarios for various combinations of systems parameters, the analysts can estimate effects in terms of expected targets destroyed. This example is from Samuelson and Sims (1995).

Lanchester differential equations have already been mentioned and I will not elaborate on that.

The idea of using information theory and entropy to measure effects of reconnaissance, intelligence and other activities related to preparing and conducting military operations seems also rather natural. Barr and Sherrel (1996) have demonstrated an application on a target detection process that makes it possible to derive a measure of information, which makes it possible to assess the value of new sensors in a way more general than the specific scenarios from which they are derived.

The examples above use conventional mathematics. There are huge amounts of models of that kind.

Dodd and Richardson (1996) gives an examination on some newer analytical and mathematical approaches, which could be useful for modeling information processes in the context of future conflict operations. The aim is to develop analytical methods for those processes that can be represented mathematically as transformations from inputs to outputs. They find that top-down detailed descriptions, for example traditional *artificial intelligence* (AI) knowledge-based methods, must be comprehensive so that every possible eventuality is covered. Maintenance of internal consistency within the rule set is often a problem.

A *Systems Dynamics* model can be developed quickly from an influence diagram using commercial tools. The main difficulty is the detailed differential equations that must be well specified.

Self-learning algorithms – for example neuronal networks – are able to generalize well if they are trained on large amounts of data, which span the range of relevant space. It is also desirable to have a well-designed network structure.

Military decisions by their very nature are often undertaken in conditions of extreme stress. Add to that the uncertainties in tactical and operational objectives in the chain of command, reliability and credibility of intelligence reports and fuzziness in the boundary regions and it is clear why military command and decision-making is due for further research.

There are other newer mathematical methods like *catastrophe theory*, *complexity theory* and *intelligent automata* approaches, which could be used for modeling combat and military decision making. A further description of new mathematics for modeling as support for decision-making is given in Woodcock (2001).

All analysts are not convinced of the usefulness of advanced mathematics. Carlsen and Hamrin (2002), who have tried to evaluate some statements of Woodcock and others, do not share their enthusiasm. They find that reading good military writers – for instance prophecies by Clausewitz – is an easier way to reach understanding of the complexity in military matters.

Moffat and Witty (2002) seems to be more successful in using catastrophe theory. They have considered a mathematical model – Bayesian Decision – of decision-making and military command. They also use elementary catastrophe theory. Their conclusion is that the application of this approach has led to insights into the command process, together with simple and elegant mathematical algorithms for the representation of these aspects of the command process in simulation of conflict. Thereby they think it will be possible to avoid large and cumbersome sets of decision rules.

A reflection is that Moffat and Witty have a more thorough representation of the dueling element than the other mathematical models, which I here have commented on. The core of their analysis is the commander's perception of the force ratio. The ordinary way in most models is that the dueling element per se is not modeled! Of course the enemy is represented in most models. However, often the opposing forces are behaving according to some fixed input. Even if that data is taken from a war game, the human dueling behavior is not modeled and thereby not analyzed as thoroughly as when it is modeled.

One reason for Moffat and Witty having a higher value could be that they go deeper into modeling of human behavior. My conclusion is that the newborn analysis in decision-making and command processes may open new fields for military analysis. That turns my attention on game theory. Look at the definition of *game theory* given by Myerson (1990):

> Game theory is about analyzing situations in which two or more individuals make decisions that will influence one another's welfare.

A shorter definition is "interactive decision theory". Theories that fit into those definitions ought to be useful also for analyses on dueling aspects of conflicts. And notice that here the dueling element is built into the core of the model. In my analytical experience I have often also thought that a problem could be analyzed in a better way if I had the time to formulate a game theoretic formulation and carry on from that.

However, I find no examples in the literature. Game theory has not often been used in analysis of modern warfare, with exceptions of nuclear warfare. And the literature on game seems to be dominated by economic problems. The military examples are few and elementary. Perhaps an explanation is the distinction between zero-sum games and nonzero-sum games. War fighting tends to be considered as zero-sum games, and theory in that domain is not as rich (it is even

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trivial in many cases) as nonzero-sum games. Operations other than war and a new perspective of war given by diffuse conflicts may open a new field also for game theory in war science. Further, the definitions given above focus on problems that would be relevant for commanders of dueling forces. I think also that the techniques of Recursive Games and Games with incomplete information (Kuhn) could be given interesting military applications. Thereby the maneuvering of dueling forces might be further developed in the same way as chess players develop their ability through studies of chess theory.

However, my conclusion so far is that there are not many good examples of new mathematical methods used in analysis of war. One reason for that could be that the state of the art in military science is not yet ready for more advanced quantitative theory building. So let us look at the state of the art in military science.

9 The State of the Art in Military Science

The defense community is becoming more and more dependent on combat models – including simulation and war gaming. Around 1990 some senior analysts in the USA – insiders of the national security model-development and analysis community – separately suspected that the use of combat models could be considerably developed. They therefore conducted a study on the state of military combat modeling. A report on that study was published by Paul Davis in 1990, which had the status of a white paper prepared for the Office of the Secretary of Defense Advanced Research Projects Agency. This report is summarized in Figs. 4 and 5.

The message in that report is that there was relatively too much enthusiasm about the advances in computer performance, communications and human interfaces, and much too little interest in the substance of the models. There was a *lack of military science*.

The report contains several aspects of self critique from military analysts. Their effort was mainly on building and using models as tools and conducting analyses on specific questions and tasks. Minimal attention was paid to "theory" per se as well as experiments and historical analysis.

They found that there is a fundamental need for improving the true *consistency* across levels. They suggest *variable resolution models* for making it easier to do cross-resolution work. A weakness was that individuals and organizations working with high-resolution models commonly look down upon aggregated models and vice versa. It is uncommon for analysts to move back and forth among levels of resolutions and perspectives. So limiting factors are more conceptual and organizational and less due to computational capacity.

Theory building and model calibration should use low-resolution data on a high level as well as high-resolution data. However, the *bottom-up paradigm* was dominating. Further, far greater emphasis should be placed on comprehensibility and appropriate documentation. A heavier emphasis was needed on long-term funding of military combat modeling as applied science, not mere tool building.

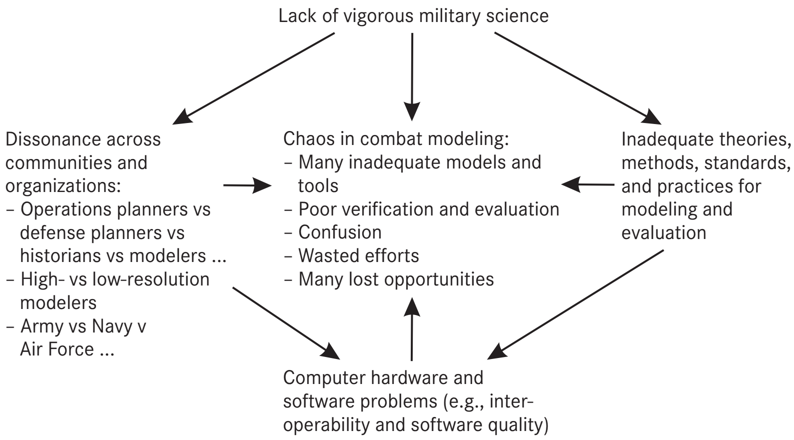

Figure 4. The state of the art in military modeling – the state 1990.

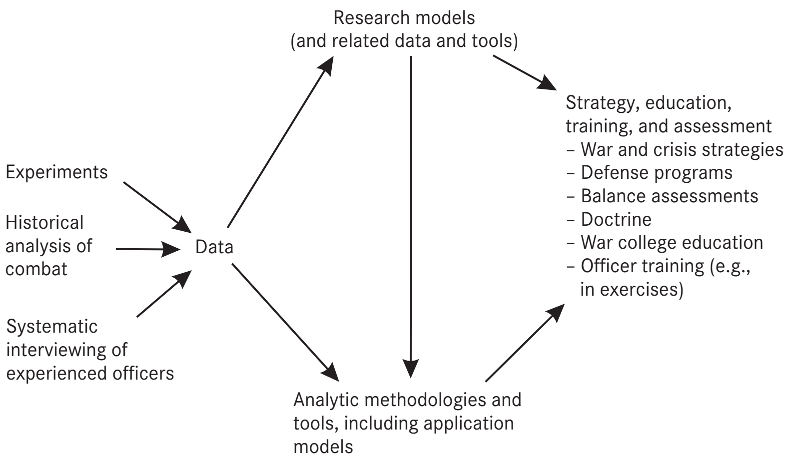

Figure 5. The state of the art in military modeling – the ideal.

There were few journals on military science. The closest was MORS journal. The academic journals of International Security and Defense analysis were of some value to military science.

Currently, the universities are of little help in developing first-rate analysts for military applications. Training centers are impressive. At the same time neither of those are appropriate places for basing scientific research, because their natural dispositions are to support here-and-now needs. Training centers give some attention to the collection of anecdotal and subjective information, but still there is much theoretical work that should be done.

As a conclusion, Davis and Blumenthal (1991) stated a need for the development of military science.

The white paper resulted in reforms in the USA. The National Defense University was reformed and strengthened to promote and nurture military science. The empirical base was strengthened and models seen as embodiment of knowledge. But the tradition of emphasizing intuitive art over science is still strong.

For some decades there has also been an international trend of academizing military officers' training. Among others, Sweden is following that trend. Lately an institution for war science is being built up within the Swedish Defense University. However, I don't think many people know the criticism and thoughts in the cited paper from 1991 in the USA. And the tradition of emphasizing intuitive art over science is still strong!

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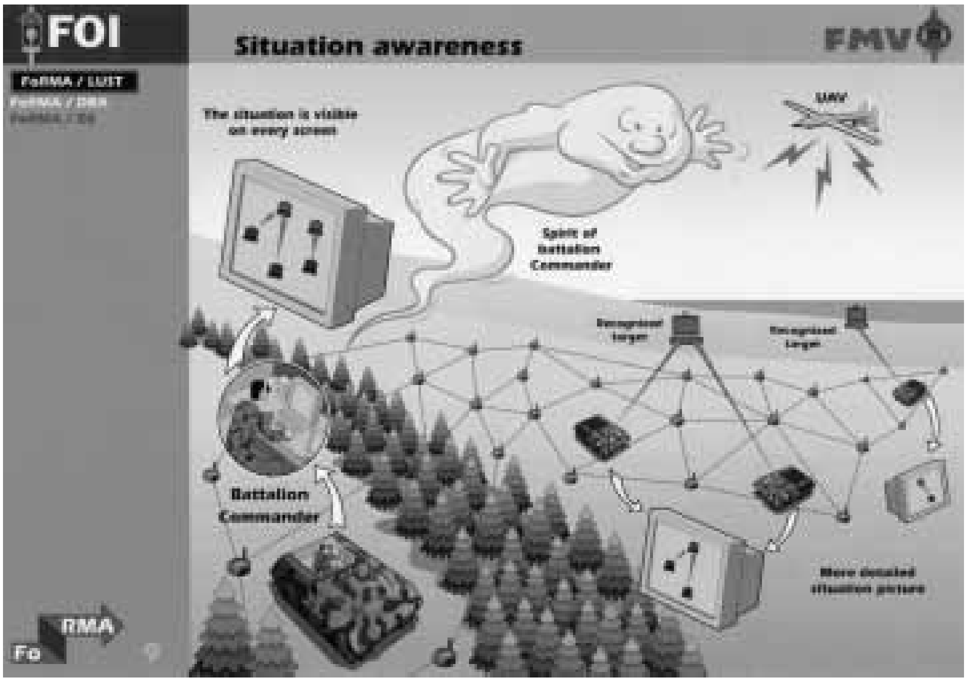

Figure 6. In real-life military analysis and planning, situation awareness is limited by low visibility of the opponent's spirit and vagueness of one's own. [Editor's note; slide: Swedish Defence Research Agency]

Gut-zu-Druck: 5.8.2003

http://www.springer.com/978-3-7643-1634-1

Mathematics and War
Booß-Bavnbek, B.; Høyrup, J. (Eds.)
2003, VIII, 420 p. 79 illus., Softcover
ISBN: 978-3-7643-1634-1
A product of Birkhäuser Basel