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EFFECTIVENESS OF FORCES AND C2 IN A SEMI-CHAOTIC ENVIRONMENT - AN INTEGRATING METHODOLOGY

SUNDFØR Hans Olav

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Jan Erik Torp
Director of Research

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FORSVARETS FORSKNINGSINSTITUTT
Norwegian Defence Research Establishment
P O Box 25, NO-2027 Kjeller, Norway

FORSVARETS FORSKNINGSINSTITUTT (FFI)
Norwegian Defence Research Establishment

P O BOX 25
N0-2027 KJELLER, NORWAY

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8) ABSTRACT

The effect of C2 on force effectiveness is given substantial attention over the last decades. However, analysts are still struggling to reflect this effect. This report presents a methodology that reflects the contribution of decision-making in an analytically well-founded way, thus contributing to the understanding of the area.

Battlefield decision-making is modelled as a combination of proactive and reactive decisions. Acknowledging that a decision-maker's search and monitoring capacity is limited, a split is made between a set of alternative actions that can be planned for in advance, and a larger and more detailed set that can not. Proactive decisionmaking is modelled as a hierarchy of two-player zero-sum games that reflects the hierarchic planning and decision-making in an organisation. Reactive opportunity exploitation is modelled as variations within each game strategy, and the concept *endogenous opportunities* is introduced to account for the effect of an organisation following up low level success on a higher level. A data gathering procedure is suggested, exploiting the rigidity of organisational knowledge.

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CONTENTS

EFFECTIVENESS OF FORCES AND C2 IN A SEMI-CHAOTIC ENVIRONMENT - AN INTEGRATING METHODOLOGY

1 INTRODUCTION

This report is produced as part of FFI-Project 735/161 "Operational Concept of Land combat". It outlines a part of the project's suggested methodology for analysing land combat organisations. Over the last decades, measuring the value added by military management organisation, consisting of headquarters, staffs, infrastructure, decision procedures and so on, is a task that is given substantial attention by the OR society, as it is in civilian strategic management research. Military OR is moving towards a better understanding of how management contributes to force effectiveness, and how this can be modelled. Much of this is documented in recent conference proceedings and NATO documents such as (CCRP 1998, 2000) and NATO RTO (1999). Simulation-based approaches, such as (Dodd et al 2000) are developed as well as more analytic approaches. In civilian research, a lot of descriptive work has been done, including statistical research on databases, and more detailed studies of single firms. Cyert and March (1992), Campbell et al (1995) and Eisenhardt (1989) are examples of small sample studies, whereas Gubta (1987) has a study with a medium sized sample.

The methodology presented in this report is an operations research methodology that aims at determining the expected performance of a future organisation with certain characteristics prior to establishing the organisation. It thus allows a decision-maker to determine the profitability of *alternative investments* in management capabilities. Operations research has over the past half a century developed a number of techniques to measure the performance of a production or battle organisation executing well-defined actions. Similar techniques are used both in research and in everyday planning to estimate the performance of management organisations in terms of the time and resources spent on producing plans or decisions. Linking the two does, however, require explicit representation of the strategy content and of the decision problem. This problem has been addressed seriously only during the last one or two decades.

A methodology partly solving this problem was presented in (Sundfør 2000). However, it only accounts for those alternative actions and alternative outcomes that each decision-maker could survey effectively prior to the decision - it accounts for the surveyable uncertainty[1]. This report extends the methodology to include variations that can not be effectively surveyed - the chaotic uncertainty. Such an environment with both surveyable and chaotic uncertainty is here called semi-chaotic.

About equal space is spent on discussing the model, the formal calculations and a possible data gathering procedure. In the model discussion, a separate section presents the game hierarchy introduced in (Sundfør 2000). This report can therefore be read independently of the first.

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[1] As the terms are used in this report, "surveyable uncertainty" denotes uncertainty about which out of a surveyable set of alternatives that represent the real truth. Chaotic uncertainty is defined similarly.

2 PROBLEM OF STUDY

The presented methodology addresses the following question:
How should an organisation with given characteristics concerning assets for battle or production and for management be expected to perform in a specific context.
The fundamental question addressed by this report is thus identical to that of (Sundfør 2000). The methodology calculates absolute effectiveness. Relative effectiveness is found as difference in absolute effectiveness, and in particular, differences relative to an existing organisation represent the gain from absolute investment in management.

The methodology of (Sundfør 2000) can account only for the alternative actions that a decision-maker can survey effectively in advance. This report extends the methodology to take into account all alternative actions that are relevant to organisational performance. The extensions covered by this report are valid for most decision-situation. However, the first part of the methodology requires that the competitive environment under study represent a two-player, zero-sum situation, in order for the game value to be well-defined. Since this part of the methodology is required for the second part, similar assumptions can be made for the second part without loss of generality, but those will not be drawn upon in the text.

For a number of areas, models are available that provide an outcome for sufficiently well-defined courses of events. This is the case for battle organisations, which was addressed in (Sundfør 2000), and (McNaught 1999), (Brown 1963) (Lanchester 1914) (Mosbye 2000) are but a few examples. Such models are assumed to be available, and are not addressed by this report.

3 MODEL

The basic model is identical to that of (Sundfør 2000). The organisation's performance is assumed to be determined by two factors:

1. The organisations ability to gain a favourable output, given specific actions undertaken by the organisation, and a particular development of the environment, including actions made by other players
2. The organisations ability to undertake actions that are favourable, relative to those of the other players and the development of external factors.

The first point is a matter of production performance, whereas the second is a matter of management, as the terms are used here. It is assumed that the output for given actions is calculable.

The management process is supposed to take place in a hierarchic structure consisting of decision-making entities. An entity can be anything from a decision-making team working closely together, to separate decision processes carried out by the same person. Each of these entities has a certain scope of its decision-making, and certain resources to administer. They reason on available information and decide on possible actions.

It is assumed that possible outcomes (when considered) are assessed according to a *consistent* set of preferences. This means that the possibly incomplete set of preference governing the assessment should be extendible to a set covering all pairs of possible outcomes, with no circular preferences. By (Neuman & Morgenstern 1944) there then exists a utility function that is linear in probability, and such that all decisions that maximise the utility function are consistent with the basic set of preferences. It is further assumed that decision-makers in the studied organisation act as to maximise organisation performance based on the available information, but with strong limitations in reasoning capacity.

The main limitation to the rational behaviour of the decision-making entity (DE) is the limits in search and monitoring capacity (naturally interpreted as the reason for the hierarchic structure). This limits the number of possible future developments of the environment and the number and nature of alternative own actions that can be effectively surveyed as part of the decision-making process. This is modelled as a split between a surveyable and a non-surveyable set of alternatives. The split is made both for alternative own actions, alternative developments of the environment, and alternative consequences. In real life, the split between surveyable and non-surveyable alternatives may be fuzzy, but is here modelled as a sharp distinction. The set of surveyable alternatives is determined by the entity's search and processing capacity and, as will be discussed later, by its "common knowledge". It should therefore be regarded as a characteristic of the entity. *Surveyable uncertainty* is defined as uncertainty about which of a known or knowable set of possible states or developments that is the true one, and correspondingly which own action is the right to undertake. Non-surveyable or «chaotic» uncertainty is uncertainty about the true state or development when *almost all* alternatives are unknown.

If there are more players on the arena, these should have similar opportunities to survey the surveyable alternatives, find out which action is optimal to another player, and what an optimal own action should be accordingly. If other players can do this, the development of the environment is dependent on own optimal action. Such a situation therefore lays a mutual consistency requirement between the optimal action of a player and it's beliefs about the environment, which is the essence of game theory. The non-surveyable alternatives should, however, not be expected to be surveyed by other players. In particular, what one player can not survey, other player should not expect him to survey, and they can not work on the assumption that he will act optimally relative to the entire set of alternatives. For each player, this cuts the environment's dependency on own optimal action. What then remains is a one way dependency from what one after all knows about the environment (beliefs) to own optimal action. This is a special case of game theory, but is usually denoted «decision-theory».

The model suggests that a decision-problem is only partly given a game-theoretic treatment, and handles this by splitting the set of alternatives. A phenomenon that is poorly handled by this model will occur only if the decision-problem does not fully fall into the game-theoretic or decision-theoretic domains, and still, for some reason, the splitting mechanism is inadequate. For this situation to occur, it is required that the set of alternatives is too big to be effectively surveyable, but still so small that there is a significant *expected* overlap between the set considered by one side and the set considered by other players. At the same time, all alternatives must be differ one from another substantially enough to not allow any grouping that would split it into a surveyable set with non-surveyable variations. Although the splitting seems artificial at first sight, these requirements to a non-handled situation are fairly strong, which suggest that the model is more robust than it seems at first sight.

When alternative developments and actions can be surveyed, proactive moves is a meaningful concept. When the alternatives are unknown, however, proactive moves will make little sense, and decisions must be postponed until a situation that calls for an action, unfolds. The decision model is therefore split in a proactive and a reactive part as follows:

1. Strategies (possibly proactive) are chosen and carried out based on the surveyable alternatives. The detailed model of this is described and discussed in (Sundfør 2000).
2. In carrying out each such decision, opportunities or problems may occur, and may or may not trigger an appropriate action. Decisions to act in such a situation are called *reactive decisions*. («Not acting» will here mean to proceed according to the plan the proactive decision).

For simplicity, all situations that call for an action are hereafter called opportunities, even if they should occur as problems to the decision-maker, since they represent opportunities to improve the outcome by an action. The fact that opportunity exploitation is modelled as variations on the original strategy, is essential to the suggested analysis methodology. These variations may, however, constitute a smaller or larger part of the *actions* - e. g. may an initial strategy consist in measures that should create opportunities in an unpredictable way, whereas the main body of action comes in exploiting these.

The decision-making model for opportunity exploitation is not too different from that of the initial strategy choice. An organisation has a set of means to observe the environment, which enables it to see certain phenomena whereas other phenomena are left unobserved. Each decision-making entity will have certain monitoring capabilities, which determine the probability that it recognises certain indications of an opportunity. If it recognises such indications, it will reason (explicitly or implicitly) on the likelihood that the opportunity actually exists, that attempts to exploit it will be successful, and on the cost of exploiting it and the gain from a successful exploitation. Further, it will reason on the risk of reducing or loosing the opportunity and the possible gains from improved information by postponing the decision. It will initiate an appropriate action if it is considered favourable, and at a time when further delays are considered unfavourable. When carried out, the action may call for an answer from other players, and their decision is modelled similarly. Whether implicit (intuitive) or explicit reasoning would be the more appropriate, will depend on the decision environment.

In the calculations, optimality of decision and of decision timing will be assumed. Sub-optimal reasoning on these factors will be modelled as deviation from optimality. However, this is neglected in the further methodology description, as no effective way of relating organisational structure and content to the reasoning quality is demonstrated. Moreover, if nothing can be known of the relative sub-optimality of the various players, the expectation is parity, and in a zero-sum situation, symmetric sub-optimality will not in general alter the *expected* outcome[2]. As a consequence of this limited rationality assumption, reactive decisions

[2] This is not to reject the usefulness of studying variations in relative reasoning quality (between the two sides) to throw light on the importance of training and education as a general issue. However, as long as generic measures of reasoning quality are missing, it would be more fruitful to link judgements of reasoning quality directly to the

can be modelled as a deterministic consequence of the decision-makers perception of the situation. A stochastic dependency may be introduced without problem, but when more than one alternative action is feasible, they either have identical expected gain, or one or more are sub-optimal. The sub-optimal alternatives should not be considered, and distinguishing between several alternatives with identical expected gain would not alter the expected performance of the organisation.

So far, the single-level decision-making has been considered. As described in (Sundfør 2000) the stepwise optimisation of the initial strategy choice starts on the top of the hierarchy and is detailed out further down. Actually it starts above the organisation, by assignment of the task it is supposed to carry out, and for which the performance should be considered. This was called a «downward decision-chain». As initial decisions are maid, and entities on each level are running an operation with level-specific scopes, an opportunity may occur that triggers an action on *any* level, depending on the scope of the opportunity. After exploitation has been decided by an entity, this is carried out by a downward decision-chain through subordinate entities.

When an opportunity is successfully exploited on one level, the resulting situation may constitute an opportunity to a higher level entity. Opportunities created by lower level opportunity exploitation will here be denoted «endogenous opportunities». If the higher level entity chooses to exploit this new opportunity, it might result in an even larger opportunity, and so on. When this takes place through several levels, it is here called an «upward decision-chain».

If the number of opportunities originally available on all levels is to large to be fully exploited, endogenous opportunity creation will only add more non-exploited opportunities, and have no impact on organisational performance. However, when opportunities are sparse on higher levels, endogenous opportunities may constitute a major part of the opportunities, and upward decision-chains may then be of major importance. Upward decision-chains are fascinating since an independent decision made on a low level of the organisation, through a series of follow-up decision may turn the focus of the entire organisation.

It should be noted that according to the model, upward and downward decision-chains fill in different roles, and are not in general interchangeable. The stepwise optimisation of a downward decision-chain will under no conditions take place in an upward decision-chain as defined here. Further, as the lower level opportunity exploitation is a precondition for the higher level endogenous opportunity to become apparent (since it is non-surveyable by definition), those opportunities can not be exploited through a downward decision-chain. (One might argue that a high level entity may discover the low level opportunity, but anyone that is monitoring low level opportunities and decides whether or not to act on them, is here defined as part of the low level entity. When defining the entity hierarchy, it is therefore important that the real decision-structure is reflected, not some kind of physical or formal structure.)

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specific decision-processes. One could, e g consider whether or not (or with what probability) the decision-makers should be expected to react appropriately on certain information, or whether he/she will see through the mess of a specific picture.

4 THE GAME HIERARCHY

The game hierarchy is described in (Sundfør 2000), where the model, calculation methodology and data gathering procedure is discussed. It is a framework for calculating expected performance of an organisation competing against another organisation in a zero-sum situation when *only* surveyable alternative actions and outcomes are considered.

The hierarchy is built up through a top-down process. On each level, both sides' alternative actions are mapped, and the number of alternatives is limited by the decision-making entity's search and processing capacity. An action by player A is defined to be taken truly before an action by player B if it is observable to player B prior to B's decision on B's action. This is modelled as A making a move before B. Moves that are not ordered this way, are modelled as simultaneous. Each combination of a strategy for each side is a *strategy combination*. The performance of the organisation within each such strategy combination is either directly determinable, or the combination is detailed further as a new game on the next lower level. This lower level game results when the set of more detailed variations of each side's strategy is generated and the decision order is determined. At some level each strategy combination defines a series of actions for which an expected outcome can be determined. The game is thus fully defined, and since it is zero-sum, it has a unique value (Nash 1951, Luce & Raiffa 1957). The value of each game is then defined recursively by taking the value of a lower level game as the value of the strategy combination it is detailing. The performance measure of the organisation is thus the value of the top-level game (the «value of the hierachy»).

The hierarchy is built up through a depth-first procedure, thus exploiting the symmetries between the alternative combinations. When one branch is followed down to a determinable level, the branch is followed up again, to see if other related combinations are determinable from the first. The hierarchy that is built up might therefore consists of only a few branches that go far down, whereas the others are determined on a more aggregate level.

5 CALCULATION OF SINGLE LEVEL PERFORMANCE

This calculation takes a single strategy combination on one level of the game hierarchy as a starting point. A set of opportunities possibly occurring during the course of events will call for various actions from all players, and depending on the actions that are undertaken, the course of events and the outcome will vary. Still, this is seen as variations *within* the strategy combination. The calculation produces an adjusted value of the strategy combination. In the next section, it will be described how a number of such single level calculations together define the organisation's performance.

From a general point of view, there are no limits to what an opportunity or exploitation of it may be. The general methodology presented in this section, therefore contains operations such as «determining a certain distribution», and a theory for this must be found in each case. A specific example is, however, given in a later section.

When calculating decision-making performance in a chaotic environment, a clear distinction has to be made between performance as an opportunity occurs, performance as indications of opportunities are recognised, and performance in the environment as a whole. This corresponds to the following three steps in the suggested calculation. (Some of the sub-tasks are described in more detail afterwards).

1. Instances of relevant opportunity occurrences are detailed out in the scenario. Appropriate actions to exploit them are identified, and possible new outcomes and the corresponding probability distribution are calculated. Similarly, the same actions are applied to *false opportunities* - situations that can be *misinterpreted* as opportunities - and outcomes are calculated accordingly. The value of each outcome and the expected value for each of the situations are determined. It is further determined whether the various outcomes should be considered as endogenous opportunities to a higher level.
2. The relative occurrence frequency of real and false opportunities, is determined for each set of detected opportunity indications. The expected value of acting on these indications is then calculated based on the relative frequency and the assessed value of the outcomes. The value of the situation when the specific set of indications are recognised, is then taken as the largest of the expected value of acting and the expected value of not acting.
3. The probability of occurrence of alternative sequences of opportunity indications is determined. Based on this and the probability for each indication to be recognised by the entity, one calculates the probabilities for each combination of recognised indications. This distribution further determines optimal decision timing, and the expected performance in the scenario can be calculated.

The performance in the scenario is now the integral over all patterns of opportunity indications, of the value at the optimal decision-point, weighted with the probability for each pattern. As it is determined whether the outcome of each opportunity exploitation represents an opportunity to a higher level, and the pattern of occurrence of each type of opportunity exploitation is determined in step three, the set of endogenous opportunities to the higher level is determined.

A few points in the three steps need some explanation: The outcome of all relevant courses of events must be determinable in step one. This includes various combinations of opportunity exploitation either in parallel or sequence, as long as they are feasible. It also includes sequential or parallel opportunity exploitation by different players. A high expected number of opportunity occurrences combined with strong non-linearity in the action-outcome relation may therefore strongly increase the complexity of the study.

The outcome of a sequence of actions on a high level may not be directly calculable by available methods and other calculated outcomes. If this is the case, the scenario should be detailed out through a local game hierarchy. It is built up as described in the last section, and represents the downward decision-chain of carrying out the decided action. This hierarchy is local to the specific instance of an opportunity occurrence, and is not added to the existing game hierarchy. The value of exploiting the opportunity (instance) is then the value of the local game-hierarchy.

Optimal timing should be determined in step three, and is defined as follows: The value of the option to act is defined as in point 2 for any observed set of indications within a scenario. The probability distribution over alternative sequences of indications determines a probability distribution over future opportunity indications for any history of indications, and an expected future value of the option to act can be calculated. The optimal time for the decision is when no future expected value of the option to act is higher than the present value. For further discussion and theory it is referred to an option theory text. (Dixit and Pindyck 1994) is suggested since it applies the theory to *real options*, not to different from the *acting option* of this report. However, one should not in general expect to be able to map opportunity occurrences into e. g. wiener processes, and the main body of results in option theory may therefore be inapplicable.

The described calculation is comprehensive, and one should be careful to take full advantage of any symmetries, similarities or other conditions that allow simplifying the problem. One important simplification is to group the relevant opportunities into classes that can be studied simultaneously by parameter variations. Further, the real and the false opportunities may be a consequence of the same unpredictable phenomenon, and modelling this as one stochastic process will ease the calculation of both relative and absolute frequencies. A third example goes on the timing problem - quite a few real opportunities can be approximated well by assuming they set a deadline for actions to be effective, and the optimal timing is to be just in time for this dead-line. If no simplifying moves are possible, the described analysis may not be practically doable, which indicates that the organisation's performance in the given situation can not (in general) be analysed.

The calculations outlined above requires a series of inputs, which has to be determined based on the scenario and the capabilities of the various organisations under study. These are:

- The nature of all relevant opportunities
- The phenomena that each organisation can «see»
- The relative and absolute occurrences of real and false opportunities
- An appropriate action that the organisation can undertake to exploit each opportunity
- The probability that indications of each opportunity are recognised as opportunity indications

Further, it is required that outcomes for sufficiently well-defined sequences of actions and events can be calculated, and that the value of a sufficiently well-defined situation can be assessed.

The calculations yield two outputs: First, an adjusted value for the strategy combination, different from the value of the corresponding lower level game. Second, a set of alternative sequences of generated endogenous opportunities with a corresponding probability distribution.

6 CALCULATIONS OF HIERARCHY PERFORMANCE

The hierarchic calculation partly consists of aggregating the effect of single level opportunity exploitation within each strategy combination, partly it consists of accounting for the opportunities created on lower level in calculating performance on a higher level.

The analysis is based on an established hierarchy of games consisting of surveyable alternatives. To each player in each strategy combination a set of opportunities is associated, consisting of opportunities that are either general to the scenario, a consequence of the strategy combination, or a consequence of lower level activities. The two first kinds of opportunities are input to the calculation, whereas the last kind is endogenous.

The calculation is an iterative process working on the outcome value of each strategy combination, not on the game structure or the game value calculation. In each strategy combination, the decision-making entity of all sides in the game will face the various opportunities, and the way these can be exploited within the predefined strategy will change the outcome and the value of the strategy combination. This is added as an adjustment to the value of the combination, which is initially set as the value of the lower level game. Further, the exploitation of opportunities within a strategy combination might create opportunities for a higher level. This is added to the higher level set of endogenous opportunities. The probability for each such opportunity to be created within a strategy combination is multiplied with the probability of that particular strategy combination in the optimal mixed strategy combination of the game (with adjusted matrix values) to find its contribution to the set of endogenous opportunities. To avoid double counting of the endogenous opportunities, the utility of each outcome should be assessed explicitly assuming that created opportunities are not exploited further on a higher level. Since these outcomes are modelled as the basis for the decision, this assumption will yield a sub-optimality in the hierarchic decision-making. This reflects that each decision-making entity can not take into account possible consequences of their actions that exceed their own actual scope.

The analysis should start from the bottom of the established game hierarchy. Wherever the other outcomes are determined based on the outcomes of the deepest branches, the deepest ones should be examined first. Each time an adjusted value of a strategy combination is found, it is sought for other strategy combinations on the same level that can be determined based on this result and the value of the initial strategy combination. This is to take as much advantage as possible of the possibility of generalising results, which is even more crucial in this part of the methodology than in the build up of the games. In an ideal case, it could be sufficient to explicitly study only one strategy combination on each level. The outcomes of «leaf-nodes» are determinable, directly or from other outcomes when only surveyable strategies are concerned. This does not necessarily mean they are determinable when non-surveyable opportunities are included. Wherever necessary, leaf-nodes may therefore be detailed further (as games) before opportunity exploitation is included.

It is reasonable to believe that the possibility of opportunity exploitation (likelihood and nature) can be foreseen in the decision-making, although each single opportunity can not. Opportunities can then be taken into account when choosing strategy proactively. This is reflected by taking the *value* of the adjusted game as input to the higher level outcome matrix. If the structure under consideration is not supposed to be able to take such opportunities into account, this is reflected by a different input to the higher level matrix. It is taken as the expected outcome, given the optimal (mixed) strategies of the non-adjusted game and the alternative outcomes of the adjusted game.

When all strategy combinations are detailed to a level where the outcomes can be calculated including the effects of non-surveyable opportunities, the hierarchy of values again constitutes a well-founded three if the effects can be calculated effectively on each level. The adjusted value on the top level is the organisation's performance. If the input can be provided, the algorithm of the last section will calculate the single level performance and the contribution to higher level endogenous opportunities. By assumption the performance for a sufficiently detailed sequence of actions is determinable - in particular it is reasonable that there exists experience on sufficiently low levels. One should therefore expect that the tree is really well-founded. The adjusted value of the hierarchy is then well-defined.

7 ESTIMATING PREDICTABILITY OF OPENINGS IN ENEMY DEPLOYMENT IN LAND COMBAT

This section illustrate how the occurrences and predictability of a particular class of opportunities can be estimated. During a study of alternative management capabilities in a land combat organisation, it was found that gaps in enemy deployment represent important opportunities, since an attack can be directed through this gap to avoid decisive resistance in an early and vulnerable phase of an operation. The study followed the steps suggested above (Sundfør 1997a, 1997b).

In a particular scenario, the combat took place between two constantly manoeuvring sides. As the units (each consisting of a large number of personnel and vehicles) manoeuvred, unintended gaps occurred when two units temporarily deviated from average speed or direction independently of each other. This was modelled as a chaotic component of the operation. As seen from decision-making entities on one level, the units' manoeuvring had a planned component - the chosen strategy for both sides on that level - and a chaotic component generated by a stochastic process with zero mean. The planned component is by definition surveyable, and accounted for in the game-hierarchy, so the unsurveyable opportunities arise from the chaotic component.

The stochastic process was estimated by mapping phenomena that would cause such unplanned behaviour. Experienced officers would typically know the nature of such phenomena, so data could be elicited, both about their qualitative and quantitative nature. Examples of these were regular changes between movement and rest, independent accidents delaying a unit or sub-unit, local variations in mobility or general deviation from expected mobility in a region. None of these gave rise to Brownian or other well-known processes, but it was still found analytical expressions representing the standard deviation as a function of time, and the large number of independent phenomena suggested that the probability distribution would be close to a normal distribution.

In step one of the calculations, detailed scenarios were developed describing successful attacks trough weak points of enemy deployment, and attacks trough the same regions with various degrees of resistance. This both reflected action on false opportunities and countermoves by the other side. The outcomes were calculated for various sequences of successful and non-successful attacks, and the value of each outcome was assessed. Further, as the outcome of an operation was a situation defined by the position and strength of the various forces, it could be established by judgement whether this state should be considered further as an opportunity on higher level.

The observable parameters were positions and velocities of both sides' units at the time of observation. The opportunities on their part were determined by the forces relative positions at the time when the operation was effective. As it is the same stochastic process that both create opportunities, and make prospective opportunities turn out to fail, both step two and three of the analysis could have been based on this process.

In step two, the probability that a prospective gap (of a certain size) in the deployment should turn out to be a gap, was estimated. It was set as the probability that none of the units forming the bounds of the gap should deviate more than half the expected size of the gap towards the centre of the gap. Since the normal distribution was assumed, and the standard deviation was given as a function of time from observation, this probability was well-defined as a function of the time-span between the last observation considered in the decision, and the time the operation had effect.

The occurrences of opportunities could now be determined e. g. by simulation of the stochastic process with an intended deployment as initial conditions. This was, however, not done in the referred study. Instead, the frequency of recognised opportunity indications was estimated directly, through scenario discussions, a methodology that effectively elicits experience. The optimal timing problem was trivial, since the units were expected to move into the gap at certain times, thereby setting a deadline for the operation to be effective.

8 MAIN CHALLENGES IN DATA GATHERING

Under the section on calculation of single level performance, an extensive list of required input is presented. Most of them will be resource consuming, particularly when the number of levels and strategy combinations is large. Some of them are, however more methodologically challenging than others.

To determine which phenomena an organisation can see and which it can not is mainly a question of analysing its means for observation, and should not be a major challenge. The necessary resources or cost of the action, and the reaction time can similarly be determined from the characteristics of the organisation, the action and the scenario. If high level characteristics of the organisation is unavailable, a method to aggregate low level characteristics is given in (Berg and Bergene 1997) and (Bergene 1998). The probability that indications are recognised can be found by experiment in a synthetic environment. All these points are resource consuming, but hardly major methodological challenges. Further, there may exist expert experience, that can be elicited and used directly without aggregation.

There remain two main challenges in the data gathering. The first is to get a *complete* picture of the relevant opportunities, their nature and pattern of occurrence. The other is to map the set of false opportunities to find their relative frequency. Although each decision on opportunity exploitation is modelled as reactive, and less open-ended than the initial strategy choice, this aspect of the scenario - the situation where the set of alternative developments can by no means be surveyed, is highly open-ended. The mechanisms that may allow gathering these data, are those limiting openness of the situation, and the study design should be designed to take advantage of these.

Although opportunities can not by definition be surveyed in advance as single instances, they may be surveyable as classes. A set of such classes can be defined, that can be surveyed at least with the time and resources available to a study. It will be argued that opportunities belonging to a class of this set are more likely to be effectively exploited than others. There are, however, limits to the validity of this argument, and attempts have been made to highlight these.

The requirement of the opportunity to be relevant to the study includes that it is somewhat likely both that it occurs and that it is exploited, and further, that acting to exploit this opportunity based on observable indications will give a significant gain. If an opportunity does not fill these requirements, it will not contribute to the calculated performance, and may be neglected in the study. In order to be consciously exploited, an opportunity must both be seen and recognised, and the organisation must be capable of carrying out appropriate actions to exploit it. It is believed that a sufficiently thorough study of today's environment will reveal the main body of future occurring opportunities. Further, it is argued that the present organisation from which the future organisation will be formed, similarly will determine the main body of what the future organisation will be able to recognise and to do.

There is a general impression that the environment of our organisations is changing. One can not get data on future fundamentally new phenomena, so such changes represent a limit to solving the problem of study. However, the fact that there are changes, does not mean that the main body of fundamental characteristics is changing. It is therefore likely that the further one digs into fundamental mechanisms, the more persistent should the characteristics be, and the less dependent on time and situation should any results be.

Kogut and Zander (1992) argue that the knowledge of an organisation is persistent over time, and strongly determines what the organisation can do. One could argue that in high-speed environments this could be slightly strengthened: The organisation should have a body of knowledge that is common to all main decision-makers, partly because it is codified, and partly because it is strongly internalised. This should determine the organisation's abilities for three different reasons.

- First, single decision-makers or teams will reason most efficiently when the reasoning only requires recombining known concepts.
- Second, each subordinate decision-maker should understand their role and know how to carry out and co-ordinate their sub-task.
- Last, a common language, again referring to common concepts is required to effectively communicate plans and roles.

It is argued in (Sundfør 2000) that this common knowledge will determine the set of feasible actions in a downward decision-chain. Since high level opportunity exploitation entails a downward decision-chain, it should hold there as well, in particular since opportunity exploitation is generally more time critical than planned action. However, the argument is weakened, and may fail for lower level opportunity exploitation.

Empirical evidence can be found, that further supports the theory. Haanes and Fjeldstad (1999) bring evidence that organisations' capability for superior opportunity exploitation is limited to certain classes of opportunities and actions. Further, their findings indicate that these capabilities can not be changed freely over time as the nature of opportunities change, and that one can not combine the full spectre of capabilities in one organisation. Their case - the pharmaceutical industries - is one with medium time frame, as opposed to the argument in (Sundfør 2000) that should hold for military operations with time frames from hours to weeks.

The chance of discovering something that one is looking for, is far greater than the chance of discovering something unexpected. As pointed out by Boisot (1998), a scanning process where neither the data nor the process is structured to reveal particular facts, is highly inefficient in discovering such facts. However, it does from time to time reveal new and unexpected opportunities, and is an important part of Boisot's «social learning cycle» (SLC). It may thus be concluded that the future shared knowledge of the organisation together with fundamental facts about the environment will determine the main body of relevant opportunities.

Boisot (1998) provides a theory for the mechanisms forming shared knowledge, and thereby explains most of the rigidity of the shared knowledge. The social learning cycle consists of six transformation steps: Scanning, Problem-solving, Abstraction, Diffusion, Absorption and Impacting, where the last step leads to shared and applicable knowledge. A procedure that is able to gather data on knowledge in the early stages in addition to those already part of the shared knowledge, should give a reliable picture of the knowledge rather far into the future. The more concrete time-span will depend on the context.

The framework of Boisot also gives an understanding for what a study will normally not capture. At any point in time, information will pass through the learning cycle in the organisation. Each instance of a decision-situation is part of the scanning process, and might reveal new knowledge, that although it is still fuzzy, can in part be used in the decision. In the problem-solving stage, personal, tacit knowledge may be used in the «owner» decision-making. The same takes place in the absorption phase. Although a methodology may capture the future shared knowledge, it can not capture the knowledge that enters the cycle in the future. One should, however, have in mind that although personal knowledge is used, it is hard to communicate, and other executives may be unable to carry out unfamiliar sub-tasks. Its impact may therefore be limited.

A move that might partly solve this problem is to define a class of «surprising opportunities». If a lot of past experience is available, this might yield data on occurrence frequency, gained performance and visibility of this class. However, even these opportunities have in common that they occurred in past environments, they were recognised by past organisations (or at least contemporary analysts). Any shift in the fundamental nature of the environment, or in organisations capabilities in catching opportunities, can produce relevant opportunities for which samples of past opportunities are not representative. James March (1995) describes this as organisational «mutations».

9 DATA GATHERING PROCEDURE

This section will describe a methodology to gather information on the set of relevant opportunities, the corresponding set of false opportunities, and the set of actions appropriate to exploit the opportunities. Modelling work will be required to determine the nature of occurrences of both true and false opportunities. This will be specific to the class of opportunities under consideration, and no attempt will be made here to formulate a general opportunity model.

As the identified limitation to openness of the future decision-situation is the future knowledge of the organisation, and this again is believed to be mainly determined by the knowledge of today's organisation, experts of today's organisation will be the main data-source. One would like to elicit both today's shared knowledge, which will almost automatically be part of the future shared knowledge, and the personal uncodified or codified knowledge of a panel of central players in the organisation. The personal knowledge of people who are expected to be central in the organisation during its future development is likely to be transformed (at least partly) to shared knowledge in the organisation under study.

To elicit today's shared knowledge does not require a panel, but rather one or two skilled people. One should, however use a review panel to determine thoroughly whether each point is commonly agreed on. To elicit personal codified knowledge, on the other hand, the process has to include the one or two persons owning each piece of knowledge, and therefore requires a larger panel. Personal non-codified knowledge may - according to Boisot - be used in creative problem-solving, and if this shall be included too, the eliciting process should therefore include problem-solving on a work-shop format[3].

A methodology consisting of a number of steps is suggested:

1. The main classes of opportunities are identified as instances by an expert panel discussing (gaming) through one or two courses of events (taken from the game hierarchy). Ideas to opportunities whose nature and relevance are less clear to participants are recorded.
2. Appropriate actions are identified, and coherent courses of events developed (possibly as a local game hierarchy). Alternative outcomes are determined, and it is assessed whether they represent endogenous opportunities.
3. A preliminary model is developed, describing opportunity classes and predicting the nature and visibility of indications and the pattern of real and false opportunity occurrences.
4. Step 2 and 3 are iterated for different combinations of initial strategies, and for different levels. On each iteration it is sought for symmetries that suggest other adjusted values to be determinable from the existing one. Eventually a preliminary hierarchy value is calculated.
5. The developed scenarios, models and resulting sets of opportunities associated to the game hierarchy is reviewed by an expert panel. The suggested similarities of step four are reviewed similarly. Step 2 through 5 are iterated if serious shortcomings are identified.

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[3] One should be aware that this process is not necessarily a passive observation of the knowledge of the organisation. A thorough study of the described sort may boost the social learning cycle, both by forcing people to be explicit on their ideas, to apply them, and by facilitating learning through collective problem-solving.

6. Games are arranged to develop coherent instances of exploitation of the less clear opportunities.
7. Outcomes, feasibility and uniqueness of those are assessed, and if they are relevant and not included by other classes, they are added to the set of instances, and step 3 to 5 are iterated.

Step 1, 5 and 6 includes a panel of experts, whereas step 2, 3, 4 and 7 includes an analyst and one dedicated expert. Further, step 1 to 5 should take care of opportunities that are part of today's shared knowledge, and step 6 and 7 are added to take care of today's personal knowledge of some central experts in the organisation. The main methodological difference is that any experienced person working closely with the analyst should be able to provide necessary input on what is shared knowledge. On the other hand, each expert has to contribute his or her own personal knowledge to reflect the present organisational knowledge on exploiting opportunities that draw on personal knowledge. Step 4 may seem odd to the data gathering procedure, but the degree of generality is an important characteristic of the set of opportunities, and should therefore bee seen as part of the data on the nature and occurrence of opportunities.

When running through the scenario at step one, the panel should be introduced thoroughly to the concept of an opportunity. At each time-step they are asked for opportunities that do occur in the scenario, or opportunities that could have occurred in this type of situation. On each such opportunity it is asked for the main characteristic of the situation and the action it calls for. It is further asked for suggestions on an abstract class-description, on how the opportunity is indicated and on how indications are observed. Any input on this should be reflected in the modelling work at step 3.

If the appropriate actions on the level under study yield a sequence of events whose outcome can not be determined, a local game hierarchy should be developed in step 2. This is again reviewed in step 5 in the same manner as the main game hierarchy.

The modelling work of step 3 may constitute a huge task, and as discussed earlier, this depends on the nature of each class of opportunities. Modelling is expected to be the analysts' domain, whereas the expert knows the phenomena to be modelled, and the co-operation should be tight. Further, as the analyst will have a leading role in the modelling process, it is important that each part of the work is reviewed by a panel of experts not influenced by the modelling process (step 5). In the panel review, the resulting sets of opportunities should be discussed relative to each strategy-combination on each level of the game hierarchy. On each such combination it should be asked for feasibility of the results, for preconditions in the model that fail in the given situation, and for opportunities that might occur, but that are missing.

Reviewing opportunities may come out with the conclusion that one ore more situations could have been surveyed by the decision-making entity, thus suggesting those be added to the set of surveyable alternatives. If this is considered to alter the expected performance, the hierarchy of both games and opportunities should be adjusted to include the new strategy.

10 CONCLUSIONS

An extension of the methodology presented in (Sundfør 2000) is provided. Where the former methodology leads to an expected performance of an organisation as a function of production and management capabilities when only surveyable alternatives are considered, the extended methodology will take into account both those alternatives that can be surveyed, and those that can not.

The methodology takes the game-hierarchy of (Sundfør 2000). The value of strategy combinations is recursively altered as one takes into account the consequences of each side's ability to act appropriately in unforeseen situations. Such situations that call for an action without having been surveyed in advance are called opportunities.

Opportunity exploitation is basically modelled as variations *within* each strategy combination. However, two mechanisms account for the hierarchic effects: First, as opportunity exploitation is carried out through subordinate entities and the outcome may not be directly determinable, local game hierarchies (local to the opportunity instance) can be built distinct from the main hierarchy. Second, as successful opportunity exploitation on one level may lead to opportunities on a higher level, bookkeeping on such endogenous opportunities is introduced, that recursively defines the set of opportunities faced by each level.

A three-step calculation procedure for the performance within a predefined strategy combination is suggested. It follows an intuitive line, taking the study from performance on exploiting a certain opportunity, via performance on exploiting a perceived, but uncertain opportunity, to performance in an environment where uncertain opportunities may be observed. Although intuitive, it is still seen that the calculations may become comprehensive. This is even more the case when the number of levels and the number of strategy combinations to be studied on each level are large. Simplification is therefore suggested along two paths: First, the classes of opportunities should be described as general and abstract as possible to allow for maximal generalisation of results within each strategy combination. Second, particular attention should be given to symmetries and similarities in the game hierarchy, which allows generalisation of results from one strategy combination to another. In addition, some situations require less analysis than others, thus leaving some of the seemingly comprehensive tasks of the methodology with trivial answers.

If such simplification is impossible, the analysis may turn out to be undoable, and this may look like a weakness to the methodology. However, the methodology allows for almost any simplification, and if the problem under study - the organisation and its environment - can not be simplified, it simply *can not* be simplified, no matter which methodology is used. The methodology is therefore a general one. On the other hand, it does not provide the models and calculations necessary to describe a given environment (except from one presented example). Neither does it provide any specific simplification that makes it practically doable to study a specific organisation in that environment. Further research is needed to fill in these holes for various organisations and environments.

There are also situations that are not handled by the methodology. One example is situations where the split between surveyable and non-surveyable alternatives is artificial. A more important class is those where the value of the game hierarchy is undefined, which is often the case in situations that are not zero-sum, and there are several Nash-equilibria. The methodology presented in this report does not rely on the zero-sum assumption, but requires an established game hierarchy with a well-defined value.

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