A Game-Theoretic Methodology Integrating Weapon And C2 Contributions To Force Effectiveness

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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 paper presents a methodology that reflects the contribution of decision-making in an analytically well-founded way, thus contributing to the understanding of the area. Battle is modelled as a hierarchy of two-player zero-sum games that reflects the hierarchic decision-making in a hierarchic organisation. In each game, operational concepts and battle capabilities determine each side's alternative actions, and C2 capabilities determine the order in which decisions and sub-decisions are to be made. The strength of game theory is used to define the game value as the measure of effectiveness. Finally, a data gathering procedure is suggested, exploiting the rigidity of organisational knowledge. The presented methodology accounts for all actions and strategies that can be planned, whereas a second step will account for situations that can not be planned for.

1 Introduction

Over the past ten years, evaluating the contribution of command and control to force effectiveness is given increasing attention by operations researchers. Expected performance of staffs, sensors and communications is extensively analysed prior to investments and reorganisation, much in the same way as outcomes of battles are evaluated. The society is, however still struggling to find appropriate ways to combine performance of decision-making capabilities and performance of the means by which a decision is carried out - the battle capabilities. This report is a contribution on the way to understanding how C2 contributes to the overall force effectiveness.

The topic of this report is analysis of expected performance of a future organisation with a certain management organisation. The model and presented methodology is general, and should be applicable to any organisation. The description given here, does however focus on military (war-fighting) organisations. Operations research societies have long traditions in studying expected performance of weapon systems, production units, equipment and organisations, as measured in output, gains or end-states. A lot of techniques are developed - simulation being but one of them. The management organisation can also be seen as a production unit, producing information and decisions, which are in turn measured in amounts produced and time- or resource spent, thus yielding a framework for measuring management efficiency. This is commonly done, both in research and in the practical planning of everyday projects. There is however a mismatch in the two measures of merit - battle effectiveness and management efficiency, which it is not trivial to address adequately. This report will focus on a methodology fusing the two into an organisation effectiveness measure. It will not focus on how each of them can be found, since techniques for this are established.

2 Problem of study

The presented methodology aims at answering the following question:

How should an organisation with certain characteristics concerning assets for battle and management be expected to perform in a specific context?

By answering this question for various structures, the differences relative to a reference structure will represent the gains of relative investment in management capacities. (Relative effectiveness is found as variation on absolute effectiveness.)

The forces partly consist of a battle-structure of weapon-systems and systems supporting those, which play the same role as a production structure in civilian organisations. Partly, it consists of a command and control-structure, deciding which tasks the battle-structure shall execute.

There is a long tradition on calculating expected performance, effectiveness or outcome for various opposing battle-structures, given a sufficiently well-defined series of actions on both sides. Calculation tools are available, and the model and method not treated explicitly here. However the required degree of detail for an outcome to be determined may vary, and this is addressed through the methodology. The report will outline and discuss how to find the effect on the total performance of the command and control structure's ability to make decisions, given that an outcome can be calculated and assessed for a well-defined sequence of events.

3 Model

This section describes the underlying model of the presented methodology. First, an organisation's performance is assumed to be determined by

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 player and the development of external factors.

The first point is a matter of battle unit performance, whereas the second is a matter of C2, as the terms are used here. What a battle unit actually is, will depend on the focus of the study, and the term may denote either a single weapon or a more complex organisation. The internal C2 structure of a battle unit is by definition outside the scope of the study. The performance for given actions is left here, assuming that it is calculable.

3.1 Basic model of hierarchic decision-making

The management process is supposed to take place in a hierarchical decision-making structure, consisting of decision-making entities (staffs, teams or single persons). These are either single persons or groups of people that make decisions in common, and who are subject to limitations in processing and monitoring capacity. An entity has a certain scope for its monitoring and decision-making, and a set of resources that it either administers directly or is able to influence. These two together determine what kind of actions the entity can initiate. A high level entity will in general have the scope and resources of all its subordinates.

The decision problem is supposed to be to complex to be totally overviewed by an entity, and the process of each single decision-making entity is arranged in proactive and reactive parts. More precisely, the proactive process is limited by the monitoring and search capacity of the entity, which allows the entity to include a limited number of alternative actions and alternative consequences of these in its search for a good proactive strategy. There might, however be a large number of more detailed variations on these alternatives, both alternative own actions, actions taken by the environment, and alternative outcomes.

Partly it must be left to other entities to detail out the decision in a proactive manner, partly the entity can detail it out on its own in a reactive manner. For as the course of events unfold itself step by step, and as the opportunities reveal themselves as real situations, not as one of innumerable possibilities, it may be feasible to react to them, even though planning for it in advance is infeasible. The (possibly fuzzy) distinction between the alternatives that can be surveyed and those that can not in a real situation is here modelled as a sharp distinction that is relative to each distinct entity. In this text, uncertainty about alternatives that can be surveyed is called *surveyable* uncertainty, as opposed to *chaotic* uncertainty, where the alternatives can not be effectively surveyed. It will be argued in a later section that the shared knowledge or doctrine of the organisation will fix the set of alternatives to be surveyed.

As part of the execution of a decision, made by one entity, a subordinate entity can make new decisions that detail out the original one. Further, an entity can decide to follow up an action initiated by a lower level entity by putting new resources into the action. When a decision is detailed out through several levels, each level may exploit its full capacity for surveying alternatives within their limited scopes, and the organisation as a total will thus be able to act proactively in far more detail than would be feasible to a single decision-maker. This will be recognised as a basic mechanism in a hierarchic organisation.

In addition to directly influencing subordinate entities, an entity can influence other entities indirectly, since a decision will have some impact on the environment, and thus create a situation that other entities may react to. Thus, an entity can by its decision directly influence decisions by entities ordered below it, but in principle influence the decision of any entity indirectly. However, it will mainly influence entities with associated resources and interests, and in particular it can influence indirectly its own superiors.

When a high level decision directly initiates more detailed decisions by lower level entities, each of which considering alternatives *within* the higher level decision, these decisions are made in some kind of sequence. This sequence of decisions starting on a high level, followed up by decisions further down in the partially ordered structure, is called a *downward decision-chain*, and leads to a thoroughly planned strategy for the organisation.

A reactive decision on a low level will on the other hand not be explicitly planned for by higher level entities. Although carried out as part of a plan initiated on a higher level, such a decision may therefore create opportunities that were neither planned for nor foreseen by the higher level, and that can be handled reactively by the higher level entity. When external opportunities are sparse, this may be the main source of opportunities to high level entities, and exploiting them may again create even larger opportunities. The argument is then easily seen to be iterated, and one should from time to time expect to see chains of decisions on opportunity exploitation, where each decision creates the opportunity that is exploited through the next decision in the chain and on the next higher level. Such a chain can be denoted an *upward decision-chain*, and by this mechanism, an autonomous decision on a low level can initiate a process that eventually leads to a new strategy for the entire organisation.

The methodology presented in this report will only treat downward decision-chains and uncertainty about alternatives that can be surveyed. Reactive decision-making and upward decision-chains is also considered important, and a second part of the methodology, not presented here, will handle this.

3.2 Model of battle decision-making

A battle (war-fighting) situation is characterised by both alternatives that may be surveyed, and alternatives that can not. It should fit the above description well. Further, battle in high intensity warfare is usually two sided, with strictly opposite preferences on the two sides, as opposed to the political game surrounding the battle.

Since only uncertainty that can be surveyed is taken into account, battle is modelled as a two-player zero-sum game. This reflects the opposite preferences, and the assumption that both sides has an opportunity to (explicitly or implicitly) overview and survey all alternatives in each distinct decision situation. The game-model is described in more detail in the next chapter.

The decision-making organisation perceives the environment (including own assets) by some sensor-systems, reasons on the received information ending up in a set of decisions, and initiates various actions. The actions can be sensed at various times, dependent on the sensor-system of opposing forces, and have effect at some time. "Sensor-system" is here defined to include filtering, analysis and synthesis of the situation-picture used by decision-makers.

The real reasoning process within each decision-making entity is in general not totally rational. The limitation in handling innumerable alternatives is already taken account for. Further, there will generally be a significant chance that important and feasible alternatives are not surveyed, not even implicitly, even though it is feasible to survey them all. A rough, or even implicit consideration of outcomes may lead to wrong estimates. The decision mechanism (which may or may not be a well-defined decision-rule) may lead to a decision that is not part of the optimal (mixed) strategy. Last, the decisions that are made, although part of the optimal strategy, may have a predictable bias that is evident to the opposing side.

Such reasoning limitations are modelled as deviation from optimality. It is easily taken into the calculation. However, it is not considered extensively in this paper, since no successful way of relating organisational structure to expected reasoning quality is demonstrated. Since the two-player game is symmetric, sub-optimal reasoning on both sides will, however, not influence the performance expectation, unless there are indications of relative differences in sub-optimality. Reasoning parity can therefore be seen as generally represented by the assumption that each entity reasons rationally. In general, parity is likely to be the best possible estimate of expected reasoning performance.

4 Calculation of expected performance

The expected performance of a particular organisation in a particular environment when surveyable uncertainty is taken into account is taken as the value of a zero-sum game. On each level of decision-making, the game is determined by the feasible alternative actions of both sides, and the order in which the choices have to be made. The levels are linked together by taking the value of lower level games as entries to higher level games.

On each level, order of decisions is defined as follows: One specific decision taken by one side is taken *before* some decision taken by the other side, if the choice of the first decision has come to the other side's knowledge in time to be taken into account in this other side's decision. This decision of the other side is taken *after* the first decision under those same conditions. As is seen, decisions are only partially ordered, and this is the main reason for the genuine uncertainty (about actions) when survey of alternatives is feasible. Decisions that are not ordered this way, are modelled as simultaneous.

Sensor-systems and speed of information processing and reasoning determine the order of decisions. When the set of decisions, the alternatives for each decision, the value of the outcome of each combination of alternatives and the order of the decisions are fully determined, so is the game. Since the game is zero-sum, it has a unique value (Nash 1951, Luce & Raiffa 1957), which is calculated by linear programming.

The game is hierarchically built up. Aggregated alternatives on a high level are described, and each side's ability to choose between the alternatives is determined to find the structure of the game. The outcomes for given combinations of alternative actions are however not necessarily determined directly. If the outcome can be determined based on the aggregate description only, so is done, alternatively, they are calculated as values of the games that result when each side's aggregated action is split into more detailed alternatives, and their ability to choose effectively between those is determined. The outcome of each combination of the more detailed alternatives can again be determined either directly, if that is possible, or as the value of a game on lower level. The game then forms a recursive three, provided that all outcomes can be calculated directly at *some* level.

The hierarchical structure influences the value of the game in two ways. First, under simultaneous choice, it reflects a stepwise optimisation, which is sub-optimal. Second, when the order of decisions is determined, it reflects the condition that a shift from any detailed instance x of the aggregated alternative X to an instance y of Y requires the prescribed resources for shifting from X to Y. The stepwise optimisation takes place in the downward decision-chain, and the levels of the game and those of the decision should therefore correspond. The structure of the switching cost is both the reason for and to some degree a consequence of the hierarchy of the decision-making organisation, and the model should therefore as a total be expected to be valid when game- and decision levels correspond.

5 Required input data for the calculation

The data that is needed for the sketched calculation can be divided into the following four groups:

- Description of decision-making and battle (production) organisation. The study is to determine the expected performance of a particular organisation, and this organisation has to be mapped. The description can either be on a detailed level, or on a more aggregate level.
- Environment of operation.
  Complete list of non-dominated alternatives for both sides.
  Decision-making and battle capacity of other participants
- Utility measure on alternative outcomes.
- Expected outcome for each combination of alternative actions. These outcomes are derived from the battle capacities of each side and the utility measure on the outcomes. Standard battle-models should be used for calculating the outcomes.

As mentioned in the model description, the aggregate description of the decision-making organisation includes reaction time for each considered decision, a description of what phenomena the sensor systems see, and the errors in the sensed picture. Those can be derived from a complete detailed description of the organisation. Although this is not trivial, it is doable, and this report will not explicitly address such calculation of lower level measures of merit.

Reasoning quality can be included in further detail if the relation between organisational structure and reasoning quality can be determined. However, this is usually not the case. On the other hand, the described calculation is totally symmetric, and introduction of some representative" quality level should therefore not be expected to affect the results.

A utility measure on the outcomes is necessary for game-theory to be meaningful. As will be known from [von Neuman and Morgenstern, 1944], this only requires consistency of preferences for each individual player. More precisely, it is required that a decision-maker's (possibly incomplete) set of preferences *can be extended* to a consistent and complete one (covering all pairs of outcomes).

6 Main challenges in data gathering

With a few exceptions, the methodology builds on input that can be attained by traditional OR techniques.

- The expected outcomes for well-defined courses of events and well-defined structures can be calculated by traditional battle simulation tools, e g based on [Lanchester, 1914].

- Command and control measures of effectiveness, such as what the organisation can see, and its time requirements can be found by similar techniques. [Berg & Bergene, 1997] and [Bergene 1998] describe how this may be done in a meaningful way.

Both theories and tools are available for these analysis jobs, bringing forth the necessary aggregates and outcome data. However, it should not be forgotten that this can be time consuming.

One major problem remains. All non-dominated alternative actions should be mapped. What makes this seem problematic, is that strategic decisions are in its nature somewhat open-ended, and a real mapping of all alternatives contradicts absolute openness of the decision-problem. On the other hand, absolute openness is seldom the case. The decision-problem has its limitations, which is what makes this kind of studies possible.

It is time to re-examine the assumption that surveying all alternatives is feasible to the decision-making team, which is the definition of surveyable uncertainty. It is believed that this assumption, along with the fixed force structure incorporates in it the main limitations to openness. [Kogut and Zander, 1992] discuss the knowledge of an organisation, and argue that it is persistent over time, in general hard to copy unless it is codified, and that it strongly determines what an organisation can do. Others, like [Boisot 1998] have elaborated more on the actual mechanisms behind knowledge development.

The organisation under study should have a body of knowledge that is common to all main decision-makers, partly because it is codified, partly because it is strongly internalised. There are three reasons why this should be expected to form the basis of the relevant alternative actions. All three reasons rest on the fact that military operations within a modern war-theatre are highly time-critical, with typical reaction times spanning from a few hours to some days.

1. One reason is that all the numerous participants should know how to carry out the various subtasks that form their part of the plan.

2. Second, there has to be a language in which the intentions, tasks and expected gains can be effectively communicated throughout the organisation - a language which in turn has to refer to a commonly shared set of concepts.

3. Last, each single decision-maker will reason far more efficiently when considering combinations of known concepts only. Starting from scratch by asking the fundamental questions of how a war can conceptually be won is not a task generally undertaken by someone in the line of fire (and doing so would have been highly irrational).

When [Eisenhardt, 1989] denotes planning processes lasting from three to eighteen months "fast strategic decision", it indicates that one should be careful in generalising these conclutions to all kind of strategic decision-making, since time-criticality is an important assumption in the argument. Still, it is believed that organisational conceptual knowledge will undergo only limited change even during this period of time.

A military doctrine or an operational concept can be seen as

1. A common language, facilitating communication and shared reasoning

2. A logic of operations, providing a understanding of how various parts fit together to make a whole

3. Concepts of feasible actions, as the pieces from which an operation can be designed

The doctrine may either be explicit or implicit, formal or informal. Once totally internalised in the organisation, the concept of a doctrine is seen to be more or less a paraphrase of organisational knowledge as used by [Kogut and Zander, 1992], which indicates that their argument concerning persistence and time-lags should be valid for doctrines as well.

As pointed out by Kogut and Zander the actions made possible by the organisational knowledge, may include actions to generate know-how as well as outward directed actions. Further, as an organisation can be good at learning on any such level, it might be good at finding new ways of generating knowledge, and so on. However, on each such level of renewal, the inertia will increase by orders of magnitude.

The concept of operations applied to a well-defined situation is equivalent to the set of feasible actions in that same situation, so each of them may be the initial one (chicken and egg problem). One might wish to develop the doctrine as a theory in parallel with the planning of an organisation and evaluation of it. As indicated, this is possible, since mapping of the alternatives is necessary for the study estimating expected performance. However, there is no solution, whatsoever to finding the concept of operation by an algorithm - it is a *creative* process. The study process might drive or inspire the concept building, but the commonly met wish of a scientific methodology deriving the concept from scratch is infeasible. The presented methodology is therefore not one to generate an optimal doctrine. Independently of how the operational concept emerges, its existence therefore has to be considered a precondition for the study of expected performance, and the results should be considered valid only for the assumed (set of) concepts.

Concluding the above paragraphs, feasible actions are determined by the doctrine, which is highly persistent over time. For limited planning-horizons, the doctrine should therefore at least be expected to be predictable if not constant. The set of alternatives that are surveyable to a decision-maker in the real future situation, should then be accessible to a decision-maker in the present organisation, knowing the concept of operation and given sufficient time and sufficient opportunity to explore the situation. Access to and co-operation of decision-makers of the present organisation should therefore provide the alternative actions, which is the main concern of this chapter.

When it is assumed that doctrine is only predictable, not static, some more comments have to be made, concerning this predictability. The intention of studying the problem of expected performance is to bring forth knowledge of a future organisation, in particular, to be able to say something a priori about the effect of investment. Decision-maker qualifications and training may, however be part of the future investment, and single present decision-makers may not be able to reproduce the alternatives conceivable to the future structure with better-educated decision-makers, even with sufficient time.

Since the creative process of making *genuinely* new knowledge is truly open-ended, there is no way to access future inventions. On the other hand, this process is extremely slow. As pointed out by Kogut and Zander, almost all new knowledge is brought forth by recombining existing knowledge and applying it on new areas. In addition, there is a significant time-lag from knowledge is invented till it is totally internalised and part of the organisation's repertoire. The amount of genuinely new knowledge available should then be marginal even for fairly long planning horizons, and not necessarily internalised throughout the organisation. As a result, the future knowledge of the organisation should be available even today in some form or another.

The knowledge of today's organisation that has the best chance of being internalised and adopted, is the present (explicit or implicit) thinking and ideas of core members of the organisation. This set of knowledge is then the best accessible estimate of the future organisational knowledge. It has two main sources of errors. There might come in genuinely new knowledge, and the organisation might fail to internalise the present thinking. The first error is argued to be limited, although it is fundamental, whereas the second can be reduced by assuring that those having the ideas are really core players, and that there is no universal resistance against the ideas among the other core players. Finding the core players is generally not a problem, as those are profiled organisation members. The task is then to map the union of perceived alternatives from a number of core organisation members, and at the same time stick to alternatives with some kind of support. This can be accomplished through panel discussions addressing the scenario and the alternative actions.

A last comment has to be made on significance of the data. As the union of the available knowledge is considered the best single measurement, the measured sample will necessarily be a sample of one. Had today's shared knowledge been the parameter under study, statistical analysis on variation in peoples' knowledge would make sense, but in the present case, it doesn't. On the other hand, the measurement is intended to be an organisation specific one, and the sample is then taken from a population of one too, so it is not too problematic. It is believed that splitting the information would distort the input seriously, thereby more than compensating the gains from significance testability.

7 Suggested data gathering procedure

This section will focus on build-up of the game hierarchy. In particular, data that aggregates up to lower level measures of merit, such as reaction times, reasoning capacities etc are not addressed. A procedure for this is outlined in [Berg & Bergene, 1997] and [Bergene 1998] among others. Further, since most operations researchers are skilled in battle analysis, it is not discussed how to determine battle outcomes for sufficiently precise courses of events. It is assumed that this can be determined.

The scenario under study should include a geographic area of operations, a sufficient description of the opposing side's organisation and management capabilities, and a set of major goals that can be translated to a utility function on outcomes. It is generally advised that multiple scenarios are used to reflect the true future challenge of the organisation, and since the effectiveness measure of this methodology is on the format of a utility measure, it is well suited for integration over multiple scenarios.

Based on the scenario, one should map the hierarchy of alternative actions on both sides down to a level that is sufficiently precise for outcome calculation. Four steps (possibly iterated) should be used building up the set of alternatives. Step 1 and 4 involve a panel of officers, whereas step 2 and 3 will involve one or two officers in addition to the analyst, who have to be available for a longer period of time.

1. War-gaming: Two parties are set to play against each other to create one feasible course of events as a starting point. If possible, the game is iterated.

2. Wherever required, details are fitted in to make the course of events complete and coherent.

3. A preliminary hierarchy of alternatives based on the games of the panel is produced. In an iterative step it is sought for the best counter-strategy of the available strategies on both sides on all levels of decision. On each level, the "best counter-strategy" operation is iterated as long as it produces new strategies.

4. The panel will have the hierarchy of alternatives presented for discussion. On each point where a combination of two strategies is detailed further, the preliminary alternatives are presented, and the panel is asked for their views on four points. 1) Strengths and weaknesses of the presented alternatives, 2) other alternatives, 3) outcomes, and 4) how each side may proceed to shift from one alternative to another.

5. If important new alternatives on a high level are presented in step four, step three and four are iterated.

Some more comments are needed on step three - the build up procedure of the hierarchy of alternative courses of events. Since the study is supposed to incorporate several levels of decision, the number of alternative actions and the number of combinations of those will both be huge, and measures have to be met to limit the expansion of the problem.

The decision-levels should be set to correspond to the union of the levels of the organisation and the main decision steps in the organisation's decision-making procedure. Each time a combination of alternative actions is identified, it should be determined whether an outcome can be calculated, or whether further detailing is necessary. This leads to a depth-first search for outcomes. As far as possible, it is important that dominated strategies are avoided. A judgement of the outcomes (measured in utility) should then be made, and combinations of alternatives seemingly in the optimal mixed strategies of both sides are detailed first.

The strength of the depth-first search is the symmetries that often occur in combinations of alternative actions, which makes it easy to determine the outcomes of a set of combinations, once one of them is determined. Once one outcome is determined, one should thereforee go upward through the hierarchy and at each level look for other outcomes that are determinable from the first, before a new branch is followed down to a detailed level. The scientist will necessarily have an important role in structuring this process, and keeping up the link between each practical decision-problem and the more abstract totality of the hierarchy. It is therefore important that the panel discussion comes afterwards to reduce the scientist's influence on the content of the hierarchy.

When the hierarchy of alternative actions for both sides is fully built up, the outcome of each course of events can be computed, and management efficiency for both sides is determined, all necessary input is in place. The value of the entire scenario can then be calculated as described in the calculation chapter.

8 Experience from applying the methodology

The presented methodology is developed based on previous experience from past projects [Sundfør, 1999], and in the form given here, it is only carried out for testing purposes. Several practical points can still be made on application of the methodology:

- The top-down approach to a large degree enables the analyst team to have an overview of the entire context of each single event.

- Once the concepts are perceived, the build up of the scenario is eased by the fact that no artificial certainty is forced on an uncertain decision situation.

- One should not underestimate the problems of communicating the hierarchy framework and game concepts to a panel of officers, and sufficient time should be given to this task.

- Including operational expertise in the build up of a preliminary hierarchy is crucial in order to have a good basis for panel discussion

Most important is, however, that it has proved possible to carry out the calculations and to have a fruitful discussion on alternative actions and outcomes. The methodology gives results significantly different from single course of action analyses.

9 Summary and conclusion

One part of a methodology for determining the expected performance of a future organisation dependent on its management capabilities has been outlined and discussed. The methodology is based on a decision-model with proactive decisions handling surveyable uncertainty, and reactive decisions to handle uncertainty that can not be effectively surveyed in andvance. The described methodology determines performance on proactive decision-making. Reactive decisions are not addressed. The paper has described the model of hierarchic decision-making, the calculations leading to an expected performance, and a procedure for gathering input to the calculations. Some important aspects of these have been discussed.

It is argued, without any detail in the methodology, that traditional tools and methods can calculate expected outcomes for sufficiently well-defined courses of events, and that expected management efficiency can be found for a planned organisation. The proposed methodology determines the set of surveyable alternative actions for all sides, then exploits the management efficiency data to order the decisions to a game, and exploits the outcome calculations to determine the value of each strategy combination. The game is known to have a value if it is zero-sum, and this value is taken as the performance estimate, which is in fact the definition of a game's value. It is further suggested a hierarchical structure on the game, taking the value of lower level games as the values of each strategy combination in higher level games. It is argued that this will reflect the sub-optimality of the hierarchic decisions. A single level game would correspond to global optimisation, which lacks realism.

The main challenge in gathering the input is the build up of the hierarchy of alternatives. Mapping the entire set of alternatives contradicts an assumption of the strategic decision as genuinely open-ended. It is argued that future organisational knowledge will define the set of feasible alternative actions. It is further suggested that organisational knowledge even some time into the future is limited to what the organisation today possess as ideas or sketches. This is taken as the basis for the suggested data gathering procedure, which aims at mapping the alternative actions that reflect present ideas and thinking of core participants in the organisation's doctrine development process.

The described methodology leads to a theoretically well founded estimate of an organisation's expected performance, already in the organisation design phase. It entirely reflects unpredictability of own and enemy actions, the value of information, speed and freedom of action, which can not be achieved with a deterministic or fixed course of action approach. All the elements of the methodology have been carried out in real analyses or on test cases, with promising results. In particular, it has been demonstrated that the analysis can be carried out with reasonable resources.

10 References

[Berg & Bergene, 1997] O Berg and T Bergene (1997): A Methodology for Analysing Command and Control Systems in Support of Information Age Challenges, Proceedings of the Third International Symposium on Command and Control Research and Technology, Washington, D.C., June 1997, pp. 178-185.

[Bergene, 1998] T Bergene (1998): *Analysing C2 Systems and Information Age Challenges for the Norwegian Defence*, Proceedings of the 1998 Command & Control Research & Technology Symposium, Monterey, CA, June/July 1998, pp. 410-416.

[Boisot, 1998] M H Boisot (1998): *Knowledge assets: Securing competitive advantage in the information economy*, Oxford university Press, pp 41-69, London

[Camarer, 1991] C F Camarer (1991): *Does strategy research need game theory?*, In Rumelt, Schendel and Teece (eds), Fundamental Issues in Strategy, Harvard Business School Press, Boston

[Cyert & March, 1992] R M Cyert & J G March (1992): *A Behavioural Theory of the Firm*, second edition, Blackwell Publishers Inc, Oxford.

[Dixit & Pindyck, 1994] A K Dixit & R S Pindyck (1994): *Investment Under Uncertainty*, Princeton University Press, Princeton, New Jersey.

[Eisenhardt, 1989] K M Eisenhardt (1989): *Making Fast Strategic Decisions in High-Velocity Environments*, Academy of Management Journal, 32, 543-576.

[Kogut & Zander, 1992] B Kogut and U Zander (1992): *Knowledge of the firm, Combinative capabilities and the replication of technology*, Organisation Science, 3, pp 383-397.

[Lanchester, 1914] F W Lanchester (1914): *Aircraft in warfare: the dawn of the fourth arm*, part V and VI - *the principle of concentration*, Engineering, 98.

[Luce & Raiffa 1957] R D Luce, H Raiffa (1957): *Games and Decisions*, Wiley, New York.

[McNaught, 1999] K R McNaught (1999): *The Effects of Splitting Exponential Stochastic Lanchester Battles*, Journal of the Operational Research Society, 50, 244-254.

[Nash, 1951] J F NDash (1951): *Non-cooperative games*, Annals of Mathematics, 54, 155-162.

[von Neuman & Morgenstern, 1944] J von Neuman, O Morgenstern (1944): *Theory of Games and Economic Behaviour*, Princeton University Press, Princeton.

[Sundfør, 1999] Sundfør H O (1999): *Evaluating effect of C2 on battle outcome by tracking information quality*, NATO RTO meetings proceedings 38, SAS-Symposium on Modelling and Analysis of Command and Control, Issy les Moulieaux, France, 12-14 January 1999