A Method for Analysing Status and Operational Effectiveness of Armed Forces – Support to Strategic Decision Making

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ABSTRACT

A precondition for an effective defence is a force structure that fulfils readiness requirements according to operational goals and objectives. Hence, we need knowledge about the operational status of the elements constituting the force structure. Weaknesses and shortcomings can affect the effectiveness of the elements by reducing their readiness, sustainability and interoperability. Although, knowledge about the status of the elements is important, what we really want to know is how this affects the ability of these elements to operate together in a joint operation to accomplish tasks and missions.

In this paper, we propose a method for analysing the effect of weaknesses and shortcomings on the elements of the force structure, and further link this causally to consequences for operational effectiveness in different scenarios. The aim is to enhance the knowledge of the defence force status, and to provide decision support to identify and prioritize measures to improve operational effectiveness. A previous version of this method has been used to support to the Norwegian defence staff in their decision and planning processes.

Keywords: Effectiveness; system performance; system elements; status; deviations.

1.0 INTRODUCTION

To be effective, armed forces require a force structure that meets readiness requirements, and which is capable to operate integrated as a joint system to achieve desired goals and objectives in relevant scenarios.

Weaknesses and shortcomings in the status of the system elements can have severe impact on their performance, and thus on the operational effectiveness of the defence forces. Hence, to make adequate decisions for enhancing effectiveness, we need thorough knowledge of the performance of the system elements, and of possible operational consequences in relevant scenarios. Identifying the most severe weaknesses and shortcomings allows for development and prioritization of measures to mitigate their consequences, and thus, reduction of operational risk.

In this paper, we propose a method for analysing the effect of weaknesses and shortcomings on the force structure elements, and further link this causally to consequences for operational effectiveness in different scenarios. The method comprises several steps, including a system analysis to understand the relations and dependencies between system elements (SE) operating together as a system to accomplish a mission.

In a previous version of the method, we performed more qualitative assessments of performance and effectiveness to support defence staff decision making. Based on feedback and experiences from this application, we identified a need for further development of the method and models in order to enhance our confidence to the results of the analysis. One particularly important improvement was the development of more flexible quantitative models with well-defined measures of performance and effectiveness, and a more explicit treatment of uncertainty. To achieve this aim, we have introduced stochastic models in the form of Bayesian network models.

2.0 ANALYTICAL METHOD

The aim of the method outlined in this section, is to provide a structured and traceable approach to identifying operational consequences of weaknesses and shortcomings in the defence forces. The main challenge is to relate observed deviations on status parameters such as personnel (P), materials (M), supplies (S), and command, control and information systems (C2IS) to operational consequences. For this purpose, we have developed a method comprising three main steps:

Step 1: Collect data and information about the status and deviations of relevant system elements.

Step 2: Analyse the impact of status and deviations on the performance of system elements.

Step 3: Analyse and evaluate the consequences of system element performance on operational effectiveness in selected scenarios.

In this paper, we focus on step 3. Steps 1 and 2 are briefly summarized in sections 2.1 and 2.2 below.

2.1 Step 1: Data and Information Collection

A premise for the ensuing analysis is collection of data and information to obtain knowledge about the status and deviations affecting relevant system elements. This is challenging due to the number of sources, uncertainty, and an excess of qualitative rather than quantitative information. We express the system element status in terms of the state parameters: P, M, S and C2IS, as described above. Accordingly, each system element has a state vector comprising information about their current state relative to some defined set of operational requirements. For example, the fulfilment of requirements related to personnel is assessed to be at 80 % due to deviations in personnel coverage and competence, while the fulfilment of supply requirements is assessed at 60 % due to shortages of spare parts and ammunitions.

2.2 Step 2: Performance of System Elements

The purpose of this step is to assess how the status of system elements affects their performance. We have defined four performance measures (MoP):

- Reaction time: Measures the time for a system element to be ready for operation.
- Capability: Measures the ability to perform a certain activity or task.
- Sustainment: Measures the time a system element can sustain operations.
- Interoperability: Measure the ability to cooperate with other system elements in a given operation.

To assess the impact on system element performance, we first establish a baseline value of the performance parameters by assessing the performance when the system element status is in accordance with plans and requirements, i.e. not affected by any significant deviations. By using the baseline as a reference, we can assess how the true status of the element affects its performance. Assessing the performance by comparing to a baseline, one should be aware of biases, which potentially can distort the assessment [1], [2].

In line with the requirements mentioned in the introduction, we apply probability distributions to represent the baseline and observed performance. The advantage of probability distributions is that they contain information about the uncertainty in the performance estimate. For instance, a triangular distribution is described by three parameters: minimum, maximum and the mode, and accordingly gives information on the most probable value as well as the range of possibilities. This distribution is attractive because it provides a rough model suitable when there is a lack data and other information about the distribution [3]. Input to step 3 consists of these distributions, and they are obtained by adjusting the min, max and mode from the baseline values, to reflect deviations reported by the defence forces.

2.3 Step 3: Impact on Operational Effectiveness

The aim of this step is to link the performance of system elements, estimated in step 2, to operational consequences in selected scenarios. Thus, we need to assess to what extent relevant system elements satisfy scenario requirements related to reaction time, capabilities, sustainment and interoperability, as well as how failures to satisfy these requirements affect the operational effectiveness of the system as a whole.

Initially, it is necessary to derive scenario requirements by performing a scenario analysis. The output of this analysis is a description of a military mission with pertaining objectives, tasks and a course of action (COA). The operational planning process as described in Allied command operations comprehensive operations planning directive COPD [4] inspires this approach. Using the output of the scenario analysis, we derive scenario specific requirements to tasks, activities and system elements. The joint functions or military basis functions are used to ensure that all relevant tasks and actions are included in the system description [5].

2.3.1 System Elements and Scenario Requirements

First, we need to assess to what degree the performance of relevant system elements satisfies scenario requirements. The output of this analysis is a vector with probabilities related to the performance parameters, indicating how likely it is that a system element satisfies performance requirements. Figure 1 shows the involved parameters. The performance parameters reaction time and capability are merged to one parameter indicating the capability at two points in time, the current, “observed” capability and an estimate of the capability at a reaction time requirement related to force build-up.

In the current version of the method, it is necessary to collapse the performance parameters into one variable representing the likelihood that the system element will be available for operations in the chosen scenario (see Figure 1).

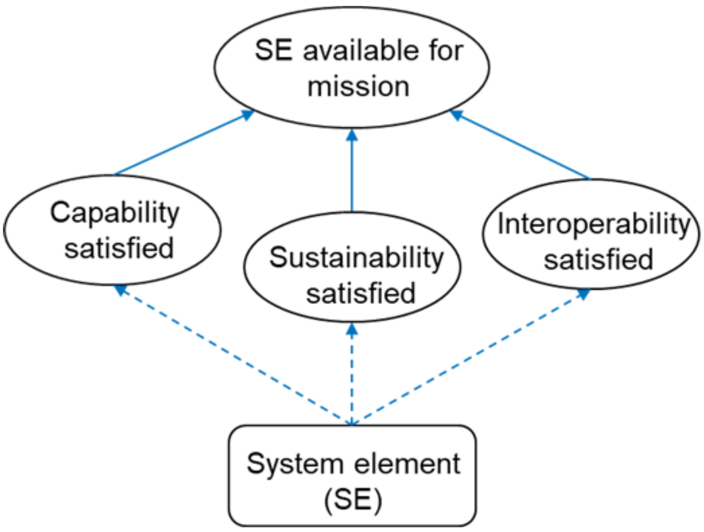


Figure 1: Bayesian network synthesis fragment to estimate the probability that a system element (SE) is available for operation.

The model shown in Figure 1 is a Bayesian network (BN) model comprising stochastic variables and dependencies. This particular model is an example of a synthesis idiom [6] where the parent variables (nodes) define the value of the child node. A BN model consists of a direct acyclic graph (DAG) where the variables and dependencies represent the joint probability distribution of the variables [7]. To every node in the network, there is an associated node probability table (NPT) containing information about the conditional probabilities between variables. In BN models with many variables and dependencies the NPTs may become large. For example, if we assume that the variables of the simple BN model shown in Figure 1 are binary, there is $2^4 = 16$ combinations of values to assess. Usually, the content of the NPTs is obtained by using available data and information in combination with expert opinions. The NPTs are scenario dependent, and it is thus necessary to revise these if the scenario is changed. We will not describe BN models any further in this paper. For more information about BN, see for instance [6], [7].

2.3.2 Consequences for Activities, Tasks and Mission

The system elements perform activities to accomplish tasks. Performing an activity according to scenario requirements may require more than one system element with the required capabilities. Hence, we need to consider capacity requirements of the capabilities. Capacity is how much of a particular capability that is needed in the scenario. In practice, we measure capacity as the number of standardized system elements with a particular capability. For example, two frigates can satisfy the scenario requirements for anti-surface warfare (ASuW) capability.

Figure 2 shows a generic model with relations between the variables: availability of system elements, activities, tasks and the mission. Accomplishment of tasks depends on one or more activities that can be interrelated. Therefore, to ensure that all relevant variables and dependencies are captured when constructing the model, one should consider the joint functions command and control (C2), intelligence (ISR), engagement (fire and manoeuvre), logistics and protection [5].

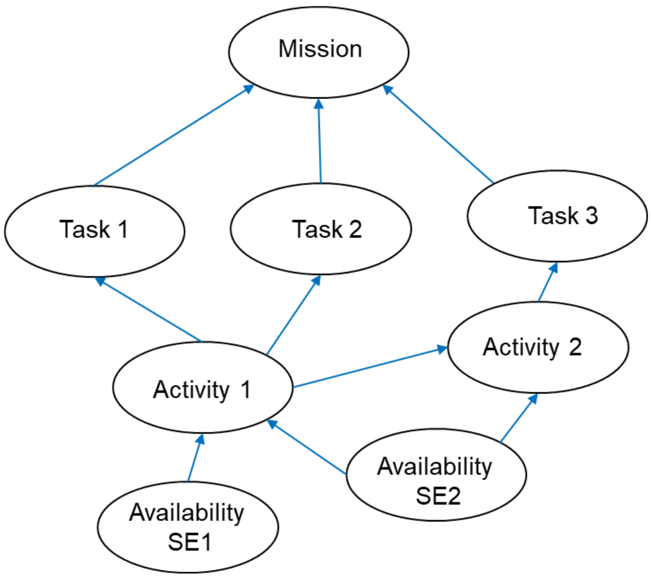


Figure 2: Generic BN model with variables related to the availability of system elements, activities, tasks and mission.

Using a BN model as shown in Figure 2 makes it possible to estimate the performance of activities, as well as the effectiveness in solving tasks and the mission as a whole. A natural choice of a high-level measure of effectiveness (MOE) is the probability of mission success.

3.0 METHOD APPLIED TO A CASE

This paper focuses on step 3 of the method outlined in section 2. Hence, for the case study we assume that steps 1 and 2 are already performed, and that the required inputs to step 3 have been generated.

The case scenario is about a raid against a littoral object. The adversary is a state actor that aims to take control of the object (e.g. a harbour/sea port). The main objective of the defence forces is to restore territorial integrity and sovereign rights by performing a mission to regain control of the object without escalating the situation further. The chosen CoA is to use a special operation task group (SOTG) to recover the object, and sea forces and home guard (HG) to protect prioritized areas in the vicinity to the object.

The first task of step 3 is to derive scenario requirements by analysing the chosen scenario and to develop a suitable system for accomplishing the mission. Comparing the performance status of relevant system elements from step 2 to the derived scenario requirements provides necessary input for calculating the probability that the system element is available for the operation. In order to use the BN model in Figure 1, we need to specify the content of the NPT belonging to the variable: system element available for operation, Table 1 (a). Table 1 (b) gives the results of the calculation.

Table 1: (a) The NPT for the variable, SE available for mission. (b) Input and output applying the BN model shown in Figure 1.

Capability	Sustain	Interoper	P(available = true)
T	T	T	1
T	T	F	0.8
T	F	T	0,9
T	F	F	0.7
F	T	T	0.4
F	F	T	0.3
F	T	F	0.1
F	F	F	0

(a)

System element	Current capability		Sustainability		Interoperability		P(SE available = T)
	Req	P()	Req	P()	Req	P()	
Operational HQ	1	1.0	NA	1.0	Own force	1,0	1.0
Tactical HQ land	1	1.0	NA	1.0	“	0,95	0.99
SOGT	1	0.95	NA	1.0	“	0,9	0.95
HG-unit	1	0.95	NA	1.0	“	0,8	0.93
ISR-unit land	1	0.9	NA	1.0	“	0,8	0.9

(b)

Table 1(b) shows a requirement for one SOTG. We estimate a probability of 0.95 for fulfilling the SOTG capability requirement. There is no requirement to sustainability in this scenario, but there is a requirement for interoperability to allow for effective cooperation with other SEs. Using the model shown in Figure 1, we obtain a probability of 0.95 for the SOTG to be available for operation. The operational HQ fulfils all requirements, and thus, the probability that the HQ will be available for operations is 1.0.

Using the generic system model shown in Figure 2, we construct a BN model for this case containing system element availability together with activities and tasks derived in the scenario and system analysis. The top node (variable) of the network is the probability of recovering the seized object.

Figure 4 shows examples of NPTs for some of the variables in the BN model. The variables have two possible states, true (T) and false (F). Note that the probability values are chosen more or less arbitrarily and are not intended to represent any realistic assessment of these probabilities.

To perform the calculations of the BN model it is recommended to use a BN tool. In this case, we have used the tool GeNIe 2.0.[1] Figure 5 shows the results of the calculation together with the NPT of the top node variable.

[1] See www.bayesfusion.com/genie

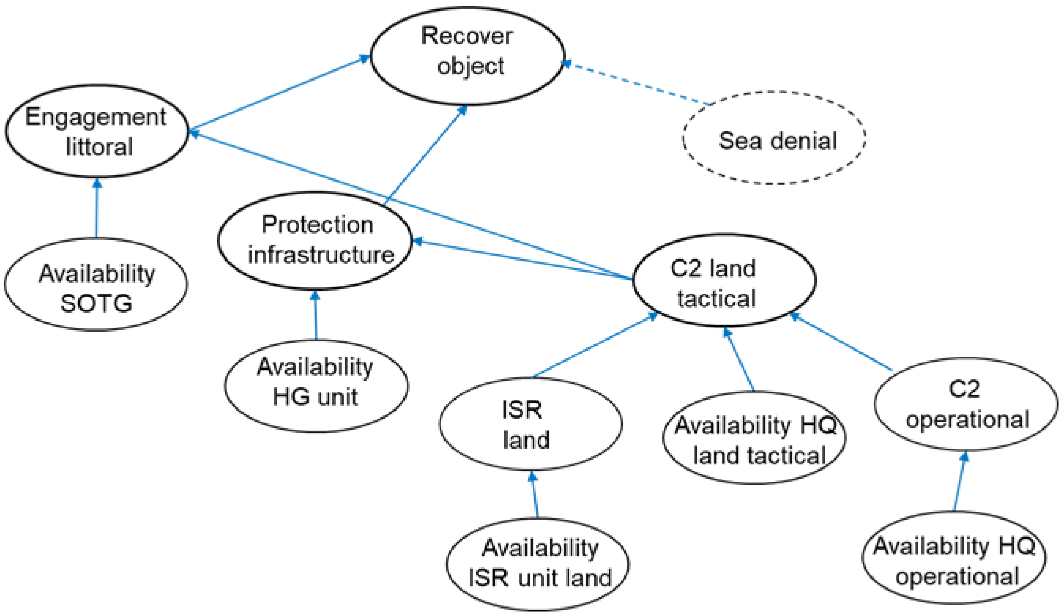


Figure 3: BN with variables related to the performance of system elements, activities, tasks and mission for the case scenario.

C2 land tactical

Tac HQ	Op HQ	ISR land	P()
T	T	T	1,0
T	T	F	0,6
T	F	T	0,8
T	F	F	0,4
F	T	T	0,5
F	F	T	0,2
F	T	F	0,3
F	F	F	0,1

Engagement littoral

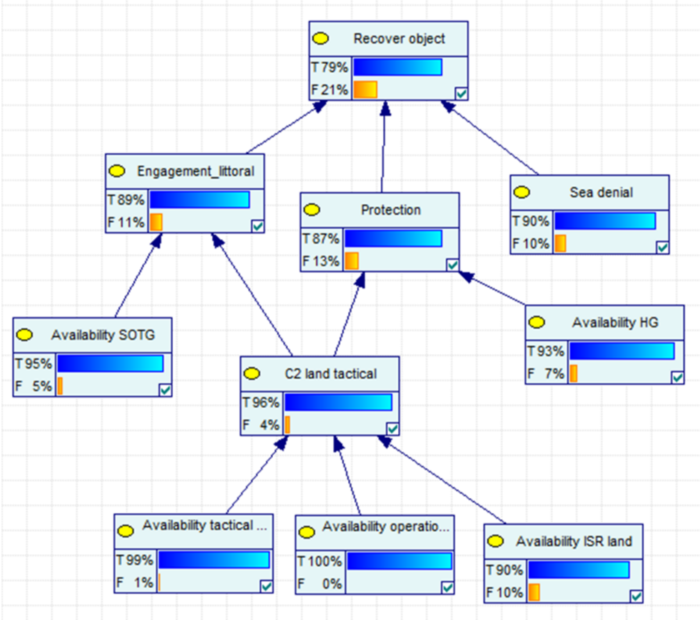
SOTG	C2 tac	P()
T	T	0,95
T	F	0,5
F	T	0,1
F	F	0,1

Protection infrastructure

HG-unit	C2 tac	P()
T	T	0,95
T	F	0,5
F	T	0,1
F	F	0,1

Figure 4: Example of NPTs for three of the variables in the BN model shown in Figure 3.

Figure 5 shows that the estimated probability of recovering the seized object is approximately 80%. Having constructed and implemented the BN model makes it easy to vary the values of the variables to explore the consequences for mission success. In this case, we have not estimated any value of the variable sea denial. Thus, the value of this variable appearing in Figure 5 is only an example and is included in the model for completeness.



Recover object

Engage littoral	Protect	Sea denial	P()
T	T	T	0,9
T	T	F	0,7
T	F	T	0,8
T	F	F	0,6
F	T	T	0,2
F	F	T	0,1
F	T	F	0,1
F	F	F	0,01

Figure 5: Results of the analysis with the NPT for the Recover object variable.

4.0 DISCUSSION AND CONCLUSION

The purpose of the method presented in this paper is to provide a structured and traceable approach to estimate the impact of weaknesses and shortcomings in the status of system elements on the operational effectiveness of the defence forces in different scenarios.

Even though the case presented in section 3 only considers a small scenario with a limited number of tasks and activities, the findings underpin that the suggested method and models are capable of providing results relevant to the analysis. However, there are issues we need to follow up further:

We need to develop steps 1 and 2 of the method further. The output from these steps is crucial for the quality of the analysis. Thus, further work is needed to ensure that the probability distributions representing the performance of the system elements are as accurate and correct as possible, i.e. that they represent the true status of the system elements. The quality of step 1, collection of data and information to establish a knowledge base, is a premise for the quality of step 2.

It is essential for the analysis that the models are sufficiently sensitive to changes in system element performance. The results of the case study indicate that the BN model with binary values of the variables is sufficiently sensitive. However, further analysis is needed to make any firm conclusions about the sensitivity of the models. Sensitivity analysis is facilitated by using BN tools like GeNIe.

Another recurring issue is validation of the models. That is, to ensure that the models provide a sufficient representation of the real systems under analysis. This is not an easy task to accomplish due to lack of data and information about missions and operations in the scenarios. Validation is even more challenging in larger, more realistic scenarios, where the models become more comprehensive with many more system elements, activities and tasks involved. A common approach for validation of this type of model is to use Subject Matter Experts (SME) with expertise on military operations to review the models.

A more comprehensive BN model with many variables and dependencies will require more and possibly larger NPTs. It is challenging to estimate all of the necessary probabilities required by large NPTs. Thus, we should look at alternative methods to define these probabilities. Fenton and Neil [6] suggest a method, ranked nodes, that seems to be promising with respect to generate larger NPTs. In addition, we should look at other methods, e.g. Monte Carlo simulation, to perform the calculations of step 3 [3].

There is an identified shortage of methods and models to assess operational consequences of weaknesses and shortcomings in the current force structure. The method and models presented in this paper are still under development. A previous version of the method has been used to support the Norwegian defence staff. We believe that the improvements presented in this paper will enhance the quality of the employed models, and accordingly the confidence in the results, thereby providing more relevant and reliable decision support for the defence staff.

5.0 REFERENCES

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