

# Scenario Development using Computer-Aided Morphological Analysis

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## ABSTRACT

Morphological analysis (MA) is a non-quantified modelling method for structuring and analysing technical, organisational and social problem complexes. It is well suited for developing scenarios, and the method is highly appropriate for complex cases where expertise from several areas needs to be involved. Using MA for problem solving or scenario generation typically involves workshop sessions supported by a computer tool. The Casper (Computer Aided Scenario and Problem Evaluation Routine) computer tool was developed at the Swedish Defence Research Agency (FOI) by Dr. Tom Ritchey in order to support MA work.

As an example of how MA is used, the development of a set of scenarios will be discussed. The scenarios were developed for the Swedish Armed Forces' long-term planning and describe a number of long-term strategic situations, including peace support operations.

## INTRODUCTION

Development of scenarios is a common task within military analysis, but one that is sometimes approached more as an art than as a science. It is not uncommon that scenarios are developed using the so-called "BOGSAT"<sup>1</sup> method, i.e. involving subject matter specialists but using a rather unstructured approach for developing the scenarios. It is not uncommon that older scenarios, generated with the "BOGSAT" method, are used as a starting point.

<sup>1</sup>

"Bunch Of Guys Sitting Around a Table."

A more structured method, which we have found useful for scenario development, is *morphological analysis* (MA). It is also useful for several other applications, such as general problem structuring. As some steps in MA benefit greatly from graphic presentation techniques, and other steps require much calculation, the method is considerably easier to apply when supported by a computer implementation. CASPER (Computer Aided Scenario and Problem Evaluation Routine) is such an implementation. MA and different versions of CASPER have been used successfully at FOI (previously FOA) for scenario generation and problem solving for a number of defence-related and other clients since the mid-90s. Dr. Tom Ritchey at FOI has been responsible for developing CASPER and the use of morphological analysis at FOI and in Sweden<sup>2</sup> (Ritchey, 1997; Ritchey, 1998).

### WHAT IS MORPHOLOGICAL ANALYSIS?

Morphological analysis is a non-quantified modelling method for structuring and analysing technological, organisational and social problem complexes. It relies on the representation of a problem using a number of parameters (or variables), which are allowed to assume a number of conditions (or states). This is the analysis phase of MA. From these parameters, consistent configurations (alternatives) are derived by considering the consistency between conditions for different parameters in a pair-wise fashion. This is the synthesis phase.

The strength of the method lies in its ability to model problem complexes in a non-quantitative manner, and, using the terminology of Pidd, in assisting in transforming “messes”<sup>3</sup> into “problems” (Pidd, 1996). Problem complexes where MA is useful typically contain non-resolvable uncertainties, cannot be causally modelled or simulated, and require a judgmental approach. For this reason, morphological analysis is used in workshop sessions with experts and problem-owners. These workshop sessions are facilitated by a person knowledgeable in the method.

Morphological analysis, or *Morphologie* in German, was pioneered by the Swiss-born astrophysics professor Fritz Zwicky (1898-1974), who was active at California Institute of Technology, and who made important discoveries in the field of supernovae. (Zwicky, 1966; Ritchey, 1998) Morphological analysis has also been applied to scenario development without the assistance of a computer tool (Rhyne, 1995; Coyle and Yong, 1995; and Johansen, 1996).

### THE MORPHOLOGICAL FIELD

In morphological analysis, a morphological field is used to represent the problem, its parameters and the conditions they can assume. The number of parameters is typically too large to represent the problem by using one spatial dimension for each parameter, as when a matrix is used to show alternatives for two parameters (e.g. four-fold tables). Therefore, each of the parameters is shown in a column, with the possible conditions as boxes in the column (Figure 1).

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<sup>3</sup> Mess: a complex issue which does not yet have a form or recognisable set of dimensions.

Parameter X	Parameter Y	Parameter Z
X1	Y1	Z1
X2	Y2	Z2
X3	Y3	Z3
X4	Y4	
X5	Y5	

*Figure 1: The Morphological Field.*

A given configuration, where conditions are assigned to each parameter, is shown by highlighting the relevant conditions for each of the parameters. The configuration above is characterised by X3 – Y4 – Z1 and is one of  $5 * 5 * 3 = 75$  possible configurations for this morphological field.

## ANALYSIS PHASE

In the analysis phase parameters (variables) are identified, followed by ranges of conditions for each parameter. Ideally, the conditions for each variable should be chosen in such a way that they are mutually exclusive. For example, in the morphological field above, X2 and X3 shouldn't be able to coexist. In short, the product of the analysis phase is a morphological field associated with the problem at hand. In the workshop setting, the process is iterative – the initial set of parameters and conditions are typically reworked many times. (A sample morphological field from a real-life application can be found in the scenario generation example later in the paper.)

## SYNTHESIS PHASE

Our initial morphological field has a large number of possible configurations. ( $5 * 5 * 5 * 5 * 3 = 1875$  in the example found later in the paper.) The synthesis phase allows us to eliminate a large number of these. We do this by judging the consistency between conditions for different parameters. We ask “is condition 1.1 for parameter 1 consistent with condition 2.1 for parameter 2?” and so on – a pair-wise comparison. The result is entered into the cross-consistency matrix. The scale used to judge consistency can vary. As a minimum, a “yes/no” scale can be used, but a scale of 3-4 steps is usually more useful, e.g. “yes – maybe – no”. (CASPER allows different scales to be used.)

It is common to continue to modify the morphological field even during the synthesis phase. Once the workshop participants are forced to discuss the consistency of different conditions, it may turn out that they need to be formulated in a different manner, or that different parameters can be combined into one, or that one parameter needs to be split into two. It will also become obvious if different participants use terminology inconsistently when they are forced to discuss the coexistence or consistency of different conditions. Morphologists have experienced many animated discussions in this step! This step in the process also works as a kind of “garbage identifier” – poorly identified conditions can be found and eliminated.

Next, the internally consistent configurations are synthesised (CASPER performs this step). Using a computer tool, it is just a matter of pressing a button. Behind the button, algorithmically speaking, a quadratic assignment problem is solved. Output is in the form of a list of surviving configurations.

Finally, one or several configurations are used by the working group for further discussion or for the solution of the problem. From this step, it is also possible to go back to a previous step and modify the morphological field or the cross-consistency matrix.

In some cases, more than one morphological field can be used to analyse a problem complex, which may be combined at a later stage. Reasons to do this may be that the number of relevant parameters is large, or that the problem complex consists of two or more aspects, with different parameters, that to some extent are separable.

In a typical application of the method, a two-day workshop would suffice for a relatively small problem area, especially if some of the participants are familiar with the modelling method. For analysing larger, more complex problem areas, 2-5 workshops would be required. It is advantageous to spread out the workshop sessions over time, to allow participants to digest the information between sessions.

### **A SCENARIO GENERATION EXAMPLE**

As an example on how MA and CASPER can be used for scenario generation, we show the creation of a set of six “+20 year environments” and strategic level scenarios for the Swedish Armed Forces. These scenarios were for use in long-term planning (defining future force structures, capabilities and investments), and the work was done in 2000. Three of these six scenarios were peace support operations. The reason why a set of several scenarios was used was that we really can’t forecast in this time perspective, so we instead need several scenarios as a basis for war-gaming and discussions. It is therefore important to choose the scenarios in a reasonable way. Each of them needs to be consistent and plausible, and together they need to cover a reasonable variety of different developments, “to span the problem space”. As a conflicting requirement, the scenarios shouldn’t be too many, because then it will not be possible to treat all of them in the continuing analysis process. Furthermore, potential users of the scenarios may lose overview.

There is no golden rule that gives the number of scenarios needed. The complexity of the problem, the capacity to analyse the consequences of the scenarios later in the process, and the level of details in the scenarios, will all affect this number.

Morphological analysis can be of great assistance in this process, since:

- The problem space is defined in creating the morphological field.
- The workshop method involved can provide a productive forum for structured discussions between subject matter specialists of different disciplines.
- Inconsistent configurations are removed in the process.
- Having an easily accessible list of surviving configurations assists in choosing configurations to be developed into scenarios.
- The illustration of different configurations in a morphological field assists the working group in deciding how many, and which, scenarios are needed.

This problem was modelled as two morphological fields:

1. An environment matrix that covers the general political, strategic and economic developments judged to be the most relevant to the problem, and that could possibly exist in a given scenario. It consists of five parameters as shown in Table 1.
2. A conflict matrix that covers the relevant characteristics of the conflict that the Swedish armed forces are called on to handle within a scenario. It consists of four parameters as shown in Table 2.

Sweden in Europe	Russia	Relations Europe-USA (Geopolitical perspective)	Focus of European (EU) security interests	Development in poor countries
Sweden a state within "US of Europe"	Central control, aggressive and strong	Antagonism	Global peace-keeping and humanitarian ops	Stability and some economic development
Part of regionalized EU	Central control, aggressive and weak	USA weak and isolationist	Strategic interests (resources)	Status quo
Nation-state within EU	Disintegration	USA strong with other focus than Europe	Regions bordering to Europe (PSO)	Crises and wars
Nation-state with bilateral relations	Cooperative and weak	Cooperation between equals	Fortress Europe	
Weak nation-state in weak Europe	Cooperative and strong	USA leading role	No common view/focus or weak ambition	

*Table 1: An Environment Matrix.*

The two matrices were first processed separately, and then combined to obtain a combination of strategic environments and conflicts.

Location of operation	Threatened Swedish objects	Means of violence	Antagonist type
"At home"	Civilian targets in Sweden	WMD systems	Alliance/state with superpower capacity
Neighbouring region	Military targets in Sweden	Long range precision guided weapons	State/alliance
Europe and surrounding regions	Swedish operations abroad	Conventional joint forces (platforms)	Quasi-state/small state
Rest of world	Swedish interests abroad	Conventional army (platforms)	Paramilitary without territory
		Conventional army (no platforms)	International network
		Simple conventional weapons	Small group/individual
		Limited use of NRBC agents	
		IW only	

*Table 2: A conflict matrix.*

It is important to realise that these two matrices, and their cross-consistency matrices (not shown) represent the judgements of the people involved at the time the work was done, and nothing else. They are not shown here as a "truth" or a scientific result, but as an illustration how MA can be applied to a problem complex of this type.

Finally, six configurations were selected and developed into scenarios under the headings:

- Arctic Region (a warfighting scenario).
- Baltic Link (a warfighting scenario).
- European Peace Enforcement (a peace support operations scenario).
- Disintegrating Russia (a peace support operations scenario).
- Global Peace Keeping (a peace support operations scenario).
- Emerging Threats (a more or less non-military scenario)

Each of these represents a consistent set of conditions for each of the parameters in the two matrices.

In order to produce the scenarios in their final form, text and maps were produced, which is work performed without immediate assistance from morphological analysis. Despite this, the previous discussions in the MA workshops provided focus also for this part of the work.

## SOME ADDITIONAL WORDS ABOUT MA AND CASPER

It is important to realise that morphological analysis relies on judgmental input, and therefore is subject to the same limitations as all such methods. For problems where a through qualitative evaluation is needed (e.g. for analysing logistical requirements of a military operation), or where detailed modelling of temporal and spatial relationships may be needed to fully grasp the problem (e.g. evaluating the outcome of combat), morphological analysis is less suited as a one-method approach to the problem. However, more often than not, a problem suitable for quantitative methods needs to be structured before it is amenable to detailed modelling, and the results of simulations may need to be put within a larger context to be of maximum use. In such cases, it may still be of value to use MA in a part of the analysis and problem-solving process.

CASPER supports the entire MA process and provides an easy-to-understand interface to the user. It is implemented as a PC/Windows programme written in C++ and Objective Grid. The MA modelling platform was designed and implemented by FOI, initially using specific funding from the Swedish Armed Forces, and is not marketed as a commercial product. Rather, FOI has used it for commissioned research, analysis and problem solving where FOI personnel work together with clients.

The reason for this is that a successful application of morphological analysis to a “mess” requires strong facilitation by an analyst experienced in the method, and has therefore been judged to be less suitable as a “do-it-yourself” software implementation. In order for the client to be able to access the result after the problem modelling has been performed, they are provided with the simplified software MA/CASPER-Viewer. This program allows for viewing of the data and manipulating the configurations, but not for altering the matrices.

Both the method and the software have been proven in some 20 projects since the mid-90s, and the use of the method has been expanding at FOI (Ritchey, 1997; Ritchey, 1998; Almén et al., 2000; and Stenström and Ritchey, 2001). Many of these projects have been within military long-term planning and studies, or civil defence-related. Some applications have been for foreign or international customers.

In working with MA/CASPER, there are limitations in the size of the expert groups (usually not more than seven persons per facilitated group) and the number of parameters (usually not more than 12) that are possible to handle in a single field. This usually does not prevent a skilled analyst from using the tool, but rather puts some restrictions on how the MA workshop sessions are organised and led.

## CONCLUSION

Morphological Analysis/CASPER:

- Handles multi-dimensional problems with non-quantitative factors.
- Provides for a well-structured discussion about complex problems.

- Is well suited for working with groups of experts that represent different areas of competence.
- Produces an “audit trail” and documentation.
- Can be used for structuring and evaluating multidimensional problem complexes with non-quantifiable parameters.
- Is well suited for scenario generation.

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