Futures Studies using Morphological Analysis

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1. Introduction

Morphological analysis is a method for rigorously structuring and investigating the total set of relationships in inherently non-quantifiable socio-technical problem complexes (variously called "wicked problems" and "social messes"[1]). The method is carried out by developing a discrete *parameter space* of the problem complex to be investigated, and defining relationships between the parameters on the basis of internal consistency. Such an internally linked parameter space is called a *morphological field*. With proper computer support, a morphological field can be treated as an inference model.

Morphological analysis can be employed for:

- developing scenarios and scenario modeling laboratories;
- developing strategy alternatives;
- analyzing risks;
- relating means and ends in complex policy spaces;
- developing models for positional or stakeholder analysis;
- evaluating organizational structures for different tasks;
- presenting highly complex relationships in the form of comprehensible, visual models.

MA is carried out in small subject specialist groups with the strong facilitation of practiced morphologists. The ideal size of the group is six to eight participants, excluding facilitators.

2. History of the Method

The term *morphology* comes from classical Greek (*morphê*) and means the study of shape or form. Morphological analysis (MA) is concerned with the structure and arrangement of parts of an object and how these conform to create a whole or Gestalt. The "object" in question can be physical (e.g. an organism, an anatomy or an ecology), social (an organization or institution) or mental (e.g. linguistic forms, concepts or systems of ideas).

The first to use morphology as an explicitly defined scientific method was J.W. von Goethe (1749-1832), who introduced it to denote the principles of formation and transformation of organic bodies[2]. Concentrating on form and quality, rather than function and quantity, this approach produced generalizations about the combinatorial logic of biological structures.

Today, morphology is associated with a number of scientific disciplines in which formal structure is a central issue. In biology it is the study of the shape or form of organisms. In linguistics, it is the study of word formation. In geology it is associated with the characteristics, configuration and evolution of rocks and landforms.

During the late 1940s, a *generalized* form of morphological analysis was proposed by Fritz Zwicky – the Swiss-born astrophysicist and aerospace scientist working out of the California Institute of Technology (Caltech)[3]. Developed as a method for structuring and investigating the total set of relationships contained in multi-dimensional problem complexes, Zwicky applied it to such diverse fields as the classification of astrophysical objects[4] and developing new forms of propulsive power systems.[5]

From the late 1960s to the early 1990s, a limited form of MA was employed by a number of engineers, operational researchers and policy analysts for structuring complex engineering problems, developing scenarios and studying security policy options.[6] However, these earlier studies were carried out by hand or with only rudimentary computer support, which is highly time-consuming, prone to errors, and severely limits the number and range of parameters that can be treated.

In 1995, my colleagues and I at the Institution for Technology Foresight and Assessment at Totalförsvarets Forskningsinstitut (the Swedish Defense Research Agency in Stockholm, FOI) realized that general morphological analysis would never reach its full potential without *dedicated,* well-thought-out computer support. The system we began developing then – and which is presently in its forth development stage – fully supports both the analysis-synthesis cycles inherent in MA, and makes it possible to create morphological inference models.[7] Such models allow us to hypothesize varying initial conditions, define drivers and generate solutions or decision paths.

Computer-supported MA has been used for the past 15 years in some 100 projects involving the development of scenario and strategy models, organisational structures, force requirements and stakeholder analysis. Clients have included Swedish and other national government agencies, national and international NGOs and private companies.

3. How to do it

A. Basic Morphological Field

The method begins by identifying and defining the parameters[8] (or dimensions) of the problem complex to be investigated (the grey column headings) and assigning each parameter a range of relevant values or "states" (the labelled cells under the headings). A morphological field – also fittingly known as a "Zwicky box" – is constructed by setting the parameters against each other in an n-dimensional configuration space. A configuration contains one value from *each* of the parameters and thus marks out a particular state or (formal) solution in the problem complex (Figure 1, below).

If the field were small enough, the working group could examine all of the configurations in the field, in order to establish which are consistent, possible, viable, practical, interesting, etc., and which are not. In doing this, we mark out in the field a *solution space*. The solution space of a Zwickian morphological field consists of the subset of configurations which satisfy some criteria – usually the condition of internal consistency.

Parameter A	Parameter B	Parameter C	Parameter D	Parameter E
A1	B1	C1	D1	E1
A2	B2	C2	D2	E2
A3	B3	C3		E3
A4		C4		E4
		C5		E5

Figure 1: A 5-parameter (dummy) morphological field containing 4x3x5x2x5 (=600) possible configurations – one shown.

However, a typical morphological field of 7 or 8 parameters can contain between 50,000 and 500,000 configurations, far too many to be inspected by hand. Thus the next step in the analysis-synthesis process is to examine the internal relationships between the field parameters and "reduce" the field by weeding out all mutually contradictory conditions.

		Parameter A				Parameter			Parameter C					Param	
		A1	A2	A3	A4	B1	B2	B3	C1	C2	C3	C4	C5	D1	D2
Parameter B	B1														
	B2														
	B3														
Parameter C	C1														
	C2														
	C3														
	C4														
	C5														
Parameter D	D1														
	D2														
Parameter E	E1														
	E2														
	E3														
	E4														
	E5														

Figure 2: Cross-consistency matrix for the 5-parameter morphological field in *Figure 1*. (The alternating dark and light cell groupings are only to help distinguish between different parameter groups.)

This is achieved by a process of cross-consistency assessment: all of the parameter values in the morphological field are compared with one another, pair-wise, in the manner of a cross-impact matrix (Figure 2, above). As each pair of conditions is examined, a judgment is made as to whether – or to what extent – the pair can coexist, i.e. represent a consistent relationship. Note that there is no reference here to causality, but only to internal consistency.

There are two principal types of inconsistencies involved here: purely logical contradictions (i.e. those based on the nature of the concepts involved) and empirical constraints (i.e. relationships judged be highly improbable or implausible on empirical grounds). Normative constraints can also be applied, although these must be used sparingly and clearly marked as such. One must be very careful not to allow prejudice to rule such judgments.

The technique of using pair-wise consistency relationships between conditions, in order to weed out internally contradictory configurations, is made possible by a principle of dimensionality inherent in the morphological approach. While the number of configurations in a morphological field grows "geometrically" (i.e. exponentially) with each new parameter, the number of *pair-wise relationships between conditions* grows "only" in proportion to a quadratic polynomial – more precisely the triangular number series. Naturally, there are practical limits reached even with quadratic growth. The point, however, is that a morphological field involving as many as 100,000 formal configurations requires no more than few hundred pair-wise evaluations in order to create a solution space.

When this solution space is synthesized, the resultant morphological field becomes a flexible ("what-if") inference model. With computer support, one or more parameters can be designated as "inputs" or drivers, initial conditions can be selected, and alternative "outputs" or solutions generated.

B. Building a Scenario - Strategy Laboratory

MA is especially suitable for pitting strategy models against scenarios or futures projections. In such cases, two complementary morphological fields are developed: one for generating different possible futures projections based on factors which cannot be directly controlled (an "external world" field); and one for modeling strategy or system variables which can -- more or less -- be controlled (an "internal world" or strategy field)[9]. These two fields can then be linked by cross-consistency assessments in order to establish which strategies would be most effective and flexible for different ranges of scenarios.

Two such fields are presented below. They derive from a study done for the Swedish Ministry of the Environment concerning the development of an Extended Producer Responsibility (EPR) system in Sweden[10].

Figure 3 (below) is a *scenario field* consisting of 8 parameters. It represents "external" factors which can influence or constrain a Swedish EPR system. The factors employed here generate 20,736 formal (scenario) configurations. Through a cross consistency assessment these were reduced to about 2000. Eight *specific scenario configurations,* which together covered all of the parameter states, were chosen by the working group for the study. These scenario configurations were then named and listed in the column at the far left – a scenario-name "placeholder". This is done for practical reasons, in order to keep track of specific configurations of interest. When such a placeholder is employed to define specific configurations, we call this a *closed scenario field*. When no placeholder is present, then the field is *open*.

SCENARIO	Buyer behaviour	Consumption patterns Total: Private import:	Consumer sorting behaviour (trends)	National environmental policy	Price of new raw material vs reclaimed material	Production technology: volume of materials	Technology development: reclaiming technology	EU-directives for import and export of waste
Global Crisis (Production gone wild)	Willing to pay more for green products	Total: Up Private import: Up	Voluntary (ideologically driven)	At the forefront; Holistic approach (legal & econ.)	New: High Reclaimed: High	Much less than today	Very rapid increases	Less restricted than today
Raw Material Depletion	Will to buy green, but will not pay more	Total: Status Quo Private import: Up	Will sort for compensation/ reward	At forefront, but no holistic approach (legal only)	New: High Reclaimed: Low	Somewhat less than today	Substantial increases	Same as today
Current policies (Negative trend)	No interest in buying green products	Total: Up Private import: SQ	Will sort if facing sanctions	Ideological, based on voluntary acceptance	New: Low Reclaimed: High	Same as today	Only marginal increases	More restrictive than today
Current policies (Positive trend)		Total: SQ Private import: SQ	Will resist sorting	Least possible adaptation	New: Low Reclaimed: Low			
Green-house effect (Stop emissions)								
Batman: High-tech solutions								
Dematerialised production (New materials)								
Green market (ideological paradise)								

Figure 3: An 8-parameter scenario field with a scenario "placeholder" parameter (at far left) showing 8 of the scenario configurations defined in the study. One is highlighted.

It is usually the case that 8-12 well-chosen scenario configurations will suffice to cover all of the cells (parameter states) in the scenario field, as well as defining a good conceptual spread of possible scenarios. If more scenarios are required, the process can simply be repeated. However, we have usually found it unnecessary to work with more than a dozen scenarios at a time[11].

Figure 4 (below) is a *strategy field* which also (purely coincidently) contains 8 parameters. It represents important "internal factors" of a (future) Swedish EPR system. The field generates 34,560 formal (strategy) configurations, which (through a cross consistency assessment) were subsequently reduced to about 500. An explicate strategy placeholder was not employed with this field, since we wished it to be left "open". The reason for this will be made clear below.

The scenario and strategy fields can be linked in order to test different strategies against chosen scenarios. However, fully linking these two 8-parameter fields into a 16 parameter field would result in a combined field consisting of over 700 million formal configurations. Worse still, this would produce an intimidatingly large cross-consistency matrix. Fortunately, we can get around having to work with such a large (and clumsy) field by using a condensed form of the scenarios: we simply merge the scenario "placeholder" parameter with the strategy field, as shown in Figure 5.

There are two ways to make the cross-consistency assessment between the scenario placeholder parameter and the strategy parameters – a *quick method* and a *thorough method*. The quick method involves relating each scenario, *as a gestalt*, to each of the strategy parameters. The group making these assessments should, of course, refer to the complete scenario field, but only in order to form a *total picture* of what each scenario would imply for *each state* of each strategy parameter. There is no direct assessment between the *internal states* of a scenario and the strategy parameters. This quick method is usually employed when there is limited time for group work.

EPR rules and regulations	Environmental adaptation of products	Required range of information about products	Waste sorting system	Collection system	Recycling system	Dominant EPR market for waste products	Instruments for deposition and burning
Voluntary, branch regulated	Focus on clean materials	Chemicals Material Energy	> 15 commodity groups	Very near premises	Mechanical recycling	International	Recycling: Up Energy: Down
General legislation toward individual. No monopoly.	Same mix as today	Chemicals Material	> 15 material groups	High density "bring system"	Thermal recycling	National and close international	Recycling: Up Energy: Up
General legislation toward collective Partial monopoly.	Focus on dematerialisation	Chemicals Energy	Same as today	Low density "bring system"	Chemical recycling	Local/regional	Recycling: Down Energy: Up
Finely detailed legislation (who, how & what)		Chemicals only	< 5 commodity groups		Biological recycling		Relative increase of deposition
			< 5 material groups				

Figure 4: An 8-parameter strategy field which contains about 500 consistent EPR strategies – one highlighted.

The *thorough method* goes full out and assesses the relationships between the internal states of each (defined) scenario, and the internal states of each of the strategy parameters. This requires eight times as many evaluations (since, in this case, there are eight internal elements for each scenario configuration), but is it much more rigorous and provides an interesting base for discussions (a crucial aspect of all the phases of a morphological analysis).

SCENARIO	EPR rules and regulations	Environmental adaptation of products	Required range of information about products	Waste sorting system	Collection system	Recycling system	Dominant EPR market for waste products	Instruments for deposition and burning
Global Crisis (Production gone wild)	Voluntary, branch regulated	Focus on clean materials	Chemicals Material Energy	> 15 commodity groups	Very near premises	Mechanical recycling	International	Recycling: Up Energy: Down
Raw Material Depletion	General legislation toward individual. No monopoly.	Same mix as today	Chemicals Material	> 15 material groups	High density "bring system"	Thermal recycling	National and close international	Recycling: Up Energy: Up
Current policies (Negative trend)	General legislation toward collective Partial monopoly.	Focus on dematerialisation	Chemicals Energy	Same as today	Low density "bring system"	Chemical recycling	Local/regional	Recycling: Down Energy: Up
Current policies (Positive trend)	Finely detailed legislation (who, how & what)		Chemicals only	< 5 commodity groups		Biological recycling		Relative increase of deposition
Green-house effect (Stop emissions)				< 5 material groups				
Batman: High-tech solutions								
Dematerialised production (New materials)								
Green market (ideological paradise)								

Figure 5: Linked fields. The scenario placeholder parameter is imposed on the strategy field.

C. Creating an Inference Model

In a linked morphological model, there is no automatically designated driver or independent variable. Any parameter – or set of parameters – can be designated as such. Thus anything can be designated input and anything output. For instance, instead of simply letting a scenario placeholder define a relevant strategy, one can reverse the process and let chosen states within a proposed strategy configuration designate relevant scenarios. This is the basis of an inference model: given a certain set of conditions, what is inferred with respect to other conditions in the model?

Figure 6 (below) is an example. In this case, we have essentially posited the following question to the model: "If we want to develop an EPR system based on *general legislation* and *international markets*, with emphasis on detailed *material-group sorting*, what are the other consistent (internal) conditions for such a system, and with which (external) scenarios is this system most compatible?" This feature, of being able to define any combination of conditions as inputs – even mixing external and internal conditions – gives morphological models great flexibility.

SCENARIO	EPR rules and regulations	Environmental adaptation of products	Required range of information about products	Waste sorting system	Collection system	Recycling system	Dominant EPR market for waste products	Instruments for deposition and burning
Global Crisis (Production gone wild)	Voluntary, branch regulated	Focus on clean materials	Chemicals Material Energy	> 15 commodity groups	Very near premises	Mechanical recycling	International	Recycling: Up Energy: Down
Raw Material Depletion	General legislation toward individual. No monopoly.	Same mix as today	Chemicals Material	> 15 material groups	High density "bring system"	Thermal recycling	National and close international	Recycling: Up Energy: Up
Current policies (Negative trend)	General legislation toward collective Partial monopoly.	Focus on dematerialisation	Chemicals Energy	Same as today	Low density "bring system"	Chemical recycling	Local/regional	Recycling: Down Energy: Up
Current policies (Positive trend)	Finely detailed legislation (who, how & what)		Chemicals only	< 5 commodity groups		Biological recycling		Relative increase of deposition
Green-house effect (Stop emissions)				< 5 material groups				
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Figure 6: Three strategy conditions selected (red) in order to examine which other strategy conditions are compatible (blue), and which scenarios these best match (blue in far-left "scenario" parameter).

Clients, researchers and decision makers who participate in developing morphological models are given software which allows them to run the models themselves. However, it must be stressed, that it is not the morphological model *as an end-product* which is the only important result of a morphological analysis. Much of the utility of the modeling process is the process itself. One of the implicit outcomes is a shared terminology and problem concept among the participants, and a better understanding of the wider context.

This section has described the basics of morphological analysis and of producing morphological models. A number of more advanced techniques, which have been developed during the past 5 years, are summarized in the section "Frontiers of the Method" (below).

4. Strengths and Weaknesses

Strengths. MA straddles the fence between "hard" and "soft" scientific modelling. It is built upon the basic scientific method of going through cycles of analysis and synthesis[12] and parameterizing a problem space. It defines structured variables, and thus creates a *real, dynamic* model, i.e. a linked variable space in which inputs can be given, outputs obtained, and hypotheses ("what-if" assertions) made. For this reason, MA is compatible with other modelling procedures, and can be employed as a test-bed or first step in the development of other types of models (see below).

The morphological approach has several advantages over less structured approaches. Zwicky calls MA "totality research" which, in an "unbiased way attempts to derive all the solutions of any given problem". It can help us discover new relationships or configurations which may not be so evident or which we might have overlooked by other – less structured – methods. Importantly, it encourages the identification and investigation of boundary conditions, i.e. the limits and extremes of different contexts and problem variables.

MA also has definite advantages for scientific communication and – notably – for group work. As a process, the method demands that parameters, conditions and the issues underlying these be clearly defined. Poorly defined concepts become immediately (and embarrassingly) evident when they are cross-referenced and assessed for internal consistency. In this sense, MA's cross-consistency assessment acts both as a "garbage detector" and an effective means in ironing out vague concepts and terminological differences.

Finally, MA leaves an acceptable *audit trail*. One of the main problems in working with "soft" modelling methods is that the actual process by which conclusions are drawn is often difficult to trace – i.e. we seldom have an adequate audit trail describing the process of getting from initial problem formulation to specific solutions or conclusions. Without some form of traceability we have little possibility of scientific control over results, let alone reproducibility. The persistent (software supported) documentation of each and every cross-consistency judgement in a morphological analysis creates such an audit trail.

Weaknesses. MA requires strong, experienced facilitation (if this is to be considered a weakness). Parameterizing a problem space by creating and linking structured variables is considerably more difficult and time consuming than developing an influence diagram containing "black box" variables. Without proper facilitation, it is very easy to create trivial morphological fields.

MA takes time. Meaningful morphological models cannot be created in an afternoon. Depending on the complexity of the problem and the level of ambition, developing a morphological model can take between 2 and 10 full group-workshop days. The work described here concerning EPR system strategies took 5 workshop days. We have done studies which have required up to 20 workshops under an 18 month period[13].

MA cannot be effectively carried out in groups larger than 7-8 participants, where the whole point is to foster dialog between subject specialists. The threshold of group dynamics, which separates participants talking to one another, from participants addressing a group as a whole, is astonishingly consistent at the magic number 7 plus/minus 2.

Proper morphological modeling requires dedicated computer support. Doing group work with the type of problems described in this article is virtually impossible without such support. This is why MA is only now developing into its full potential.

Finally, as with all modeling methods, the output of a morphological analysis is no better than the quality of its input. It is the responsibility of the facilitator – in collaboration with the client – to make sure that a competent group is formed, and that the MA modeling process is carried out properly. However, as described above, even here MA has some advantages. Unclear parameter definitions and incomplete ranges of conditions are immediately revealed when one begins the task of cross-consistency assessment. These assessments simply cannot be made until the morphological field is well defined and the working group is in agreement about what these definitions mean. Thus, one of the advantages of MA is creating among participants a common terminology and conceptual modeling framework.

5. Use in Combination with other Methods

Since a central feature of morphological analysis is to parameterize a problem complex, MA can be used to good advantage both as a *follow-up* to some methods, and as a *preceding step* for others. In the former case, mind mapping, the development of influence diagrams or so-called Vester sensitivity models[14] can be used in order to identify variables which can then be analyzed and linked in a morphological model.

In the latter case, the results of a morphological model can provide input for the development of other (possibly more complex) models. The connection between MA and Bayesian Network (BN) modeling is an especially interesting example. A BN is a graphical structure (technically a *diagonal acyclic graph* or DAG) representing cause-effect relationships between a number of defined variables. Each variable is assigned a range of mutually exclusive *values* or *states*, and the causal relationships between them are quantified by means of probabilities. Once a BN is quantified, it can propagate newly acquired information through the rest of the network.

MA and BN are thus closely related methods for developing inference models. Each has its advantages and disadvantages for modelling complex processes and systems. MA allows small groups of subject specialists to define, link and internally evaluate the parameters of complex problem spaces, thus creating a solution space and a flexible inference model. However, MA cannot easily treat hierarchical or network structure and causal relationships.

Bayesian Networks allow for such causal and hierarchal relationships, but they are more difficult to employ in the initial, problem formulation phase of the modelling process. Combining MA and BN, as two phases in the modelling process, allows us gain the benefits of both of these modelling methods.

When constructing a BN model, the major modelling criteria that arise are:

1. What are the variables and the ranges of variable values?
2. What does the graphical (e.g. causal) structure look like – i.e. between which variables are there dependencies and what are their causal directions?
3. What are the strengths of these dependencies, as depicted in the graphical structure?

As can immediately be seen, the first step in this process is realized in a morphological analysis. Even part of the second step is accomplished: MA's cross-consistency assessment will designate which variable pairs involve dependencies, and which do not – although it will not explicitly give a causal direction or strength.

In earlier work with Bayesian Networks, we have found that the very prospect of tackling all the three modeling steps from scratch, under limited time conditions, was truly daunting for the working group. We also found a tendency to rush into steps 2 and 3 before step 1 of the process was mature enough, causing a good deal of confusion. The whole process becomes much more tenable if it is broken up into *two conceptually distinct phases*: do a morphological analysis first, without any reference to directed causality or hierarchy, thus allowing the working group to concentrate on one main task. When this is accomplished, steps 2 and 3 in the BN modeling process follow much more easily.

Another modeling method, which can be supported by MA, is multi-criteria decision analysis. Particular solutions coming out of a morphological model, whether these are scenarios, strategies or other types of configurations, can be employed as *alternatives* in e.g. the Analytic Hierarchy Process (AHP)[15]. AHP is a method for systematically comparing alternative solutions in the context of a hierarchy of goals and goal criteria. While it is often the case that goal hierarchies are relatively easy to formulate, synthesizing a relevant range of alternative, internally consistent solutions is often not. This process can be facilitated with morphological analysis.

6. Frontiers of the Method

During the past 20 years, morphological analysis has developed from a relatively simple form of attribute listing with internal consistency checks into a method for interactive inference modelling which supports complex strategic decision-making.

With the advent of dedicated computer support for MA some 10 years ago, it has been possible to develop a number of more advanced features, which Fritz Zwicky could only have dreamed of. During the past 5 years we have been developing the following concepts and functions to enhance the application of MA.

1. *Multi-part internal evaluations*. Cross-consistency assessments done on a morphological field treat *pair-wise relationships* between parameter values. These assessments are carried out, *inter alia*, in order to identify inconsistent conditions in the parameter space, thus reducing this space and defining a solution space. However, it often happens that a pair of parameter values is consistent or inconsistent *depending on the value of a third parameter*. In many cases this causes no problem: if a pair-wise relationship is possible under *any circumstances*, then it is possible, and should not be forbidden. However, in some instances it is important for the model to explicitly account for this particular *conditional dependency*. An example is the "cumulative inconsistency" of increasing costs or other quantities that may be represented *across several parameters* at once. Our modeling system now allows for treating multi-part parameter assessments.

2. *AND-lists*. Strictly speaking, a *true variable* always consists of mutually exclusive values or states. However, it is sometimes advantageous to formulate a parameter consisting of values or states which are *not* mutually exclusive. Variables containing mutually exclusive values are called "OR-lists" (i.e. their logical relations are based on the Boolean "or" operator). Variables containing values which *can exist concurrently* are called "AND-lists". Each of the values in an AND-list can be thought of as a simple binary variable: for every other parameter value *Xi*, it is either "on" (i.e. compatible with *Xi*) or "off" (incompatible with *Xi*). AND-lists are useful for saving (parameter) space and condensing many simple "yes-no" variables. They are best used as output parameters, expressing e.g. concurrent goals or methods. However, they can also be employed in other ways.

3. *Stakeholder or position analysis*. Sets of AND-lists can be employed in a stakeholder analysis. This can be done by first formulating a conventional morphological field, such the EPR strategy field, and letting different stakeholders define their respective "positions" for each of the parameters in the field. A new field is then created by treating each stakeholder as a parameter, with the stakeholder *positions* concerning the strategy field listed beneath (see Figure 7, below). The group of (different) stakeholders then does a cross consistency assessment on this field. This is an exceedingly interesting exercise. The process can be applied to negotiations.

Stakeholder 1	Stakeholder 2	Stakeholder 3	Stakeholder 4
Stakeholder's position on parameter 1	Stakeholder's position on parameter 1	Stakeholder's position on parameter 1	Stakeholder's position on parameter 1
Stakeholder's position on parameter 2	Stakeholder's position on parameter 2	Stakeholder's position on parameter 2	Stakeholder's position on parameter 2
Stakeholder's position on parameter 3	Stakeholder's position on parameter 3	Stakeholder's position on parameter 3	Stakeholder's position on parameter 3
Stakeholder's position on parameter 4	Stakeholder's position on parameter 4	Stakeholder's position on parameter 4	Stakeholder's position on parameter 4
Stakeholder's position on parameter 5	Stakeholder's position on parameter 5	Stakeholder's position on parameter 5	Stakeholder's position on parameter 5

Figure 7: Dummy stakeholder field consisting of 4 AND-lists.

4. *Time lines*. Time can be treated in a number of ways in morphological models.

   i. *Naked time parameter*: This is a parameter which simply lists time intervals as such (e.g. within an hour, within a day, within a week, etc.). Any other parameter, which is dependent on time, can then be related to this general time parameter. It can then be used as a co-driver with any other designated driver or drivers, in order to examine a time-line or critical time points.
   ii. *Applied time parameter*: This is a parameter which measures a time line for a *specific process or event*. Any other parameter, which is dependent upon this process or event, can then be related to it.
   iii. *Parameter-wise time ordering*: In this case, some or all of the parameters in the field are ordered (left to right) in a time-line. This is used when the order of the parameters represents a time-ordered process.
   iv. *Configuration-wise time ordering*: This is a sequence of configurations which represents time-ordered development. It is especially useful for developing time-lines in scenarios.

The example in Figure 8 (below) shows how two of these time-line modes are utilized. The example is taken from a study done for the Swedish Nuclear Power Inspectorate, concerning the development of morphological models for evaluating a new spectrum of threat scenarios and alternative preparedness measures[16]. The parameter on the far left is an *applied time parameter* which steps through a scenario in 8 stages. Each step is related to a *preparedness demand configuration* (blue cluster) which develops over time. “Information assurance” is an auxiliary parameter used in order to qualify the information from the scenario parameter. The scenario concerns a terrorist attack on a Swedish nuclear facility.

Micro scenario (Time-line)	Information assurance	What command level required	Demands on quality of advice/decisions	SKI's required cooperation with others	What output required from SKI	Primary receiver of output from SKI
1. Sudden shift in threat perception	High assurance Almost real time	SKI & SSI together	Well analyzed, established advisory decision	Centralized, authority cooperation	Decisions concerning others' operations	Central government administration/PM
2. Observation of unauthorized activity outside of facility perimeter	High assurance Short delay	SSI alone	Intensified expert analysis	SKI at location in Sweden	Expert advice by external demand	Central government authorities
3. Encroachment of perimeter observed	High assurance Long delay	SKI alone	Standard expert analysis	Assistance abroad	Descriptive information by external demand	Affected county administration
4. Encroachment of vital area of inner facility	Uncertain Almost real time	Watch commander	Simple analysis with expert support	Cooperation at a distance	Expert advice at own discretion	Police
5. Aggressor take control of vital facility area	Uncertain Short delay		Real-time deliberation	None	Descriptive information at own discretion	Municipal rescue services
6. Threat is made	Uncertain Long delay				None required	SSI
7. Demands made						SKI's line organization
8. Negotiation						Directly affected organization
9. Threat is carried out						

Figure 8: Scenario field consisting of a scenario time-line (far left parameter) which steps through a series of configurations – one of which is highlighted.

5. *Relational database*. The documentation entered into the text areas associated with each cross consistency assessment can be collated into a relational database, which can then be addressed by defining drivers and configurations. This is useful when a lot of *structured information* is required in order to support a study.

6. *Linking fields*. It is possible to allow the designated output of one morphological field to become the input for another field. Alternatively, the designated output a number of (sub-) fields can be collated into a single (super-) field. This allows for a hierarchical or networked morphological model. This is useful when the model treats of several levels of abstraction.

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Endnotes

[1] See “Wicked Problems: Structuring Social Messes with Morphological Analysis” at www.swemorph.com/wp.html. The concept of *wicked problems* was first presented in Rittel H & Webber M. "Dilemmas in a General Theory of Planning," *Policy Sciences* **4**, Elsevier Scientific Publishing, Amsterdam, 1973, pp. 155-169. The concept of *social messes* was presented in Ackoff R. *Redesigning the Future,* Wiley, New York, 1974.

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[6] For engineering studies and technical forecasting see e.g.: Norris K W (1963). "The Morphological Approach to Engineering Design." (Conference on Design Methods. J. C. Jones and D. G. Thornley, eds. Elmsford, N.Y.: Pergamon Press, Inc., pp. 115-140); Ayres R U (1969). "Morphological Analysis", in Technological Forecasting and Long-range Planning, (McGraw-Hill, New York, pp. 72-93); Bridgewater, A V (1969). "Morphological Methods - Principles and Practice." (Technological Forecasting. R. V. Arnfield, ed. Conference on Technological Forecasting, University of Strathclyde, 1968. Edinburgh: University Press, pp. 241-252.) For operational research and policy studies see e.g.: Müller-Merbach H. (1976). The Use of Morphological Techniques for OR-Approaces to Problems. (Operations Research 75. Amsterdam, New York, Oxford. North-Holland Publishing Company, pp. 127-139); Rhyne, R. (1971). *Projecting Whole-Body Future Patterns - The Field Anomaly Relaxation (FAR) Method*. Educational Policy Research Center of Stanford Research Institute: Menlo Park, California; Rhyne R (1981). "Whole-Pattern Futures Projection, Using Field Anomaly Relaxation". (Technological Forecasting and Social Change 19, pp. 331-360); Rhyne, R.(1995). Evaluating Alternative Indonesian Sea-Sovereignty Systems. (Informs: Institute for Operations Research and the Management Sciences.); Coyle, R. G. *et. al.* (1994): Futures Assessments by Field Anomaly Relaxation, Futures 26(1), 25-43.

[7] FOI implements computer supported morphological analyses with *MA/Casper*. *MA/Casper* is a proprietary software system developed by FOI in order to support of the analysis-synthesis cycles inherent in morphological analysis. It has functions for defining the problem space, making internal consistency evaluations, analyzing the outcome space, performing inference operations, documenting group work and presenting the results. It was developed to facilitate interdisciplinary and cross-sector cooperation in working groups. A description of *MA/Casper* can be found at: www.swemorph.com/macarma.html.

[8] In mathematics, a parameter is one of a set of variables that expresses the coordinates of a point. More generally, however, it is one of a set of factors that define a system and determine its behavior.

[9] In futures studies it is usual to define three types of environments: the *contextual environment*, *the transactional environment* and the *strategy space*. The contextual environment is defined as those factors in the *external world*, which can influence how a system functions, but which cannot be influenced by the system. The strategy space is defined as the *internal world*, comprising those factors which the system-owner can control and mould into a strategy for coping with the external environment. However, factors can be designated as "external" or "internal" only *a potiori*. In reality, there is always some degree of overlap between these contexts. Some factors, while being external to the strategy space, can be influenced by particular aspects of a strategy. Factors, which are external to a system as such, but which can be influenced by the system, belong to the *transactional environment*.

[10] A summery, English translation of this study can be downloaded from: www.swemorph.com/pdf/epr9.pdf.

[11] Many futures researchers feel that 3-4 scenarios are optimum for studying strategy alternatives. We disagree, and feel that the number of scenarios is completely dependent on the

problem complex at hand, and the purpose of the study. We have worked with defense and security related studies, in which scores of scenarios were generated in order to be tested against a number of predefined security strategies. This can be done effectively with computer supported MA.

[12] Ritchey, T. Analysis and Synthesis – On Scientific Method based on a Study by Bernhard Riemann. Systems Research 8(4), 21-41 (1991). A Reprint can be downloaded from: www.swemorph.com/pdf/anaeng-r.pdf.

[13] This concerned the development of a suit of computerized instruments for evaluating Swedish Rescue Services' preparedness for accidents and terrorist actions involving chemical releases. The study can be downloaded from: www.swemorph.com/pdf/chem2.pdf.

[14] See http://www.frederic-vester.de/Sensitivitymodel.htm.

[15] Saaty, Thomas. Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World, RWS Publications, Pittsburgh, 2001.

[16] Ritchey, Tom. "Nuclear Facilities and Sabotage: Using Morphological Analysis as a Scenario and Strategy Development Laboratory". Adaptation of a Paper delivered to the 44th Annual Meeting of the Institute of Nuclear Materials Management - Phoenix, Arizona, July, 2003. The article can be downloaded at: www.swemorph.com/pdf/inmm-r2.pdf. This was one of several studies carried out in order to revise threat assessments in Sweden in the aftermath of September 11th, 2001.