

Problem structuring using computer-aided morphological analysis

Tom Ritchey*

Swedish Morphological Society
SE-118 69 Stockholm, Sweden.

General morphological analysis (GMA) is a method for structuring and investigating the total set of relationships contained in multi-dimensional, usually non-quantifiable, problem complexes. Pioneered by Fritz Zwicky at the California Institute of Technology in the 1930s and 40s, it relies on a constructed parameter space, linked by way of logical relationships, rather than on causal relationships and a hierarchal structure. During the past 10 years, GMA has been computerized and extended for structuring and analyzing complex policy spaces, developing futures scenarios and modelling strategy alternatives. This article gives a historical and theoretical background to GMA as a problem structuring method, compares it with a number of other “soft-OR” methods, and presents a recent application in structuring a complex policy issue. The issue involves the development of an Extended Producer Responsibility (EPR) system in Sweden.

Keywords: morphological analysis, general morphology, problem structuring methods, typology analysis, OR-methods.

NOTE: This is the complete article as published in the Journal of the Operational Research Society (JORS). However, it is the post-peer-review, pre-copyedit version and has a slightly different format. The definitive publisher-authenticated version, Ritchey, T. *Problem Structuring using computer-aided morphological analysis*, Journal of the Operational Research Society (2006) 57, 792–801, is available online at: <http://www.palgrave-journals.com/jors/journal/v57/n7/abs/2602177a.html>.

Introduction

Structuring and analyzing complex socio-technical systems presents us with a number of difficult methodological problems. Firstly, many of the factors involved are not meaningfully quantifiable, since they contain strong social, political and cognitive dimensions. Secondly, the uncertainties inherent in such problem complexes are in principle non-reducible, and often cannot be fully described or delineated. This includes both so-called agonistic uncertainty (conscious, reflective actions among competing actors) and non-specified uncertainty (for instance, uncertainties concerning what types of scientific and technological discoveries will be made in the future).

Added to this, the extreme non-linearity of social systems means that literally everything is connected to everything else. What might seem to be the most marginal of factors can, under the right historical circumstances, become a dominating force of change. All of this means that traditional quantitative methods, mathematical (functional) modelling and simulation will simply not suffice.

As an alternative to mathematical modelling and other “hard” OR methods, a number of non-quantified problem structuring methods (PSMs) have been developed during the past 30 years – mainly within the British OR community (Rosenhead, 1989). Many of these methods were developed expressly for the purpose of structuring and analysing what have variously been termed *wicked problems* (Rittel & Webber, 1973) and *social messes* (Ackoff, 1974).

* Contact: ritchey@swemorph.com

Although there are many different specific procedures and techniques employed in different PSMs, it is interesting to compare two *general approaches* to problem structuring. One of these builds upon networks and hierarchies of causal or quasi-causal relationships, which can be represented in different forms of *influence diagrams*. In general, an influence diagram is a qualitative model of a system which depicts influence relationships between different elements or aspects of the system, shows the direction of such influences and (usually, but not always) allows for feedback loops or circular causality. In some cases, influences can be given relative strengths, and flows between nodes can be mapped. In other cases, the diagrams are only pictorial representations of complex nets of interaction. Models of this type have broad applications and are widely utilised within the OR-community. Moreover, there is a flora of software packages available for their facilitation. Soft Systems Methodology (SSM) (Checkland, 1989) and Strategic Options Development and Analysis (SODA) (Eden, 1989) are examples of this general approach.

A complementary approach, which goes under the broad designation of morphological and typological methods, is based not on networks of causal relationships and hierarchal structures, but on constructed parameter spaces, linked by way of logical relationships. At least rudimentary examples of this approach are found, for example, in the Strategic Choice Approach (SCA) (Friend, 1989) and Quality Function Deployment (QFD) (Akao, 1990; Cohen, 1995).

Curiously, both morphological and typological methods were originally developed in German speaking environments in the 19th century, at which time the dichotomy between *Naturwissenschaft* and *Geisteswissenschaft* essentially mirrored the present-day methodological distinction between “hard vs. soft” scientific methods. Since its beginning, morphological analysis has been employed as a modelling method specific to a number of scientific disciplines. However, during the past 30 years, and especially with the advent of small, fast computers and advanced graphical interfaces, general morphology – or general morphological analysis (GMA) – has developed into a discipline of its own.

This article will continue with a short history of the development of general morphological analysis, a

presentation of its methodological foundations, and a case study in problem structuring involving the development of an Extended Producer Responsibility (EPR) system in Sweden. I hope to demonstrate that GMA is not at odds or in competition with other PSMs based on other principles. Indeed, straddling the fence between hard and soft OR methods, GMA should be seen as an important complement to both of these “cultures”, offering features that should help to strengthen PSMs in general.

Morphologies and typologies

The term *morphology* comes from classical Greek (*morphê*) and means the study of shape or form. Morphology 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 a physical system (e.g. an organism, an anatomy or an ecology) or a mental object (e.g. linguistic forms, concepts or systems of ideas). Today, morphology is associated with a number of scientific disciplines in which formal structure, and not necessarily quantity or function, 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.

The first to use the term *morphology* as an explicitly defined scientific method was J.W. von Goethe (1749-1832). Goethe introduced the term to denote the principles of formation and transformation of organic bodies. Concentrating on form and quality, rather than function and quantity, this approach produced generalizations about the combinatorial logic of biological structures. Of central importance was the idea of the *morphotype*; that is, a structural or organisational principle which can be identified and studied through comparative anatomy. This early theoretical morphology was eventually eclipsed by Darwinian evolutionary theory in the late 19th century.

With the exception of the works of William Bateson (1896) and D’Arcy Thompson (1917), it remained obscure until the Modern Synthesis in evolutionary biology began to treat Darwinian evolution from at the level of genes, phenotypes and populations. The present literature in theoretical

morphology is now quite extensive, as presented in McGhee (1999).

It is important to note, that Goethe developed morphology with the expressed purpose of methodologically distancing the life sciences from the then reigning paradigm in *Naturwissenschaft*, i.e. classical (Newtonian) mechanics. However, this methodological shift was exactly what was needed in another area, which was even less disposed to such a paradigm: the emerging disciplines of sociology and psychology. Theoretical morphology was thus carried over into the *Geisteswissenschaft* of Classical German Sociology – represented by Wilhelm Dilthey (1833-1891) (Dilthy, 1989) and Max Weber (1864-1920) (Weber, 1949). More specifically, morphology and morphotypes became typology and ideal types.

A typology (the Greek word *typos* originally meant a hollow mould or matrix) is a very simple morphological model based on the possible combinations obtained between a few (often two) variables, each containing a range of discrete values or states. Each of the possible combinations of variable-values in the typological field is called a *constructed type*. Typologies abound, especially in the sociological literature, and typology analysis is virtually a discipline in itself (Bailey, 1994; Doty & Glick, 1994). The simplest and most common form of a typology is the ubiquitous *four-fold table*, which pits two variables against each other, each variable containing two values or states.

The type-concept was not created by Dilthey and Weber. It was already well established methodologically by Goethe in his conception of morphotypes. However, by employing typologies as a method for formulating sociological and social philosophical categories, Weber simplified, generalised and popularised typology analysis as a simple *concept-structuring method* applicable to virtually any area of investigation. In this context, typologies are one of the most fundamental forms of problem structuring.

Although typological fields are certainly not restricted to two dimensions or simple binary relations, there are severe limits to the complexity of the classical typological format. Visually, a typology utilizes the dimensions of physical space to represent

its variables, as in a Cartesian coordinate system. Each of the constructed types lies at the intersection of two or more coordinates. However, the number of coordinates that can be represented in physical space ends at *three*. Typologies of greater dimensions – representing hyperspaces – usually get around this problem by embedding variables within each other. However, such formats quickly become difficult to interpret, if not hopelessly unintelligible. There are, however, other ways to represent – and visualize – hyperspaces.

General morphology

In the late 1940's, Fritz Zwicky, the Swiss astrophysicist and aerospace scientist based at the California Institute of Technology (Caltech), proposed a generalized form of morphological analysis:

"Attention has been called to the fact that the term morphology has long been used in many fields of science to designate research on structural interrelations - for instance in anatomy, geology, botany and biology. ... I have proposed to generalize and systematize the concept of morphological research and include not only the study of the shapes of geometrical, geological, biological, and generally material structures, but also to study the more abstract structural interrelations among phenomena, concepts, and ideas, whatever their character might be." (Zwicky, 1969, p 34)

In general morphology, the problem of representing – and visualising – a hyperspace is overcome by placing the variables in columns beside each other, their value ranges listed below them. This is called a *morphological field*. A particular constructed morphotype (called a *field configuration*) is designated by selecting a single value from each variable (Figure 1).

Zwicky published a number of articles applying morphology to the classification of astrophysical objects (Zwicky, 1948^a) and the development of jet and rocket propulsion systems (Zwicky, 1947). He also published a more general article on the "morphological method of analysis and construction" (Zwicky, 1948^b) and later – in the 1960s – wrote a book on the subject (Zwicky, 1969).

The medium through which the engine moves	The type of motion of the propellant relative to the jet engine	Physical state of propellant	Type of thrust augmentation	Type of ignition	Sequence of operations
Vacuum	Rest	Gaseous	None	Self igniting	Continuous
The atmosphere	Translatory	Liquid	Internal	External ignition	Intermittent
Large bodies of water	Oscillatory	Solid	External		
The interior of the solid surface strata of the earth	Rotatory				

Figure 1 Zwicky’s “propulsive system morphology” from 1947, containing 6 parameters and 576 formal configurations – one shown.

His morphological astronomy lead to a number of hypotheses and later discoveries, but remained more or less specific to astrophysics. His work on jet propulsion systems, however, had a wider impact in the area of engineering design.

In 1962, in a paper presented at a conference on engineering design methods in London, Norris (1963) proposed that the morphological approach should be turned into a full fledged engineering design method utilising computers, in order to systematically separate and collate different design solutions. Some authors saw even wider applications. Ayres (1969) pointed out how morphological analysis could be employed to systematically generate scenarios. He cited the work on future, non-national nuclear threats by Theodore Taylor (1967) at the Stanford Research Institute (a civilian and commercial counterpoint to RAND).

Then, in 1975, Müller-Mebach (1975) of the University of Darmstadt published an article in *Operational Research* titled “The Use of Morphological Techniques for OR-Approaches to Problems”. There he pointed out that general morphology is especially suitable for operational research, not the least because of the growing need for operational analysts to be part of the *problem formulation process*, and not simply a “receiver” of pre-defined problems.

In a more specific context, Rhyne (1971, 1981) – also from the Stanford Research Institute – picked up on Taylor’s earlier work and began to apply a somewhat restricted form of morphological analysis as a scenario development technique. (In order to generate new interest in the method, Rhyne packaged it under the somewhat esoteric name of “field anomaly relaxation” – FAR, a term borrowed from mechanical engineering [personal communication].) He continues to write about its potential as a systematic approach to “whole pattern futures projection” (Rhyne, 1995^a, 1995^b).

Finally, in the early 1990’s, Geoff Coyle, then working at the Royal Military College of Science in Shrivenham, UK, discovered Rhyne’s work and promoted morphological analysis as one of a number of structured techniques for scenario development and strategy planning (Coyle *et. al.*, 1994; Coyle, 2004).

None of this seems to have had much of an impact on OR-techniques or PSMs generally. Indeed, GMA has been written about and discussed far more than it has actually been used in “real” client-based projects. One of the principle reasons for this, I believe, is that it has been carried out by hand, or with only rudimentary computer support. Employing GMA in this way is not only extremely difficult, time consuming and prone to errors; it severely limits the number and range of parameters that can be employed. Since the number of configurations (i.e.

formal solutions) in a morphological field increases exponentially with the number of parameters applied to it, working with as few as six or seven variables becomes a considerable task. Thus, until recently, GMA has usually been carried out as a relatively simple form of attribute listing with internal consistency checks.

In 1995, my colleagues and I at the Department for Technology Foresight and Assessment at Totalförsvarets Forskningsinstitut (FOI – the Swedish Defence Research Agency in Stockholm) realized that general morphological analysis would never reach its full potential without *dedicated, flexible* computer support. The system we began developing then – and which is presently in its fourth generation – fully supports the analysis-synthesis cycles inherent in GMA, and makes it possible to create morphological inference models (Ritchey, 2003). During the past 10 years we have utilised computer aided morphological analysis in more than 50 client-based projects, for structuring complex policy and planning issues, developing scenario and strategy laboratories, and analysing organisational and stakeholder structures.

Problem structuring with GMA

As with most other PSMs, GMA goes through a number of iterative steps or phases which represent cycles of analysis and synthesis – the basic method for developing (scientific) models (Ritchey, 1991). Also, as with many other PSMs, facilitated group interaction is a central feature of the process, since we are not only structuring a complex problem, but creating among the participants shared concepts and a common modelling framework. What is essentially a process of collective creativity is best facilitated in dialog between participants, rather than each participant addressing an “assembly”. For this reason, we have found it best to work with subject specialist groups of no more than 6-7 persons. If a wider knowledge base is required, one can either bring specialised competence into specific group sessions, or work in parallel groups.

Depending on the level of ambition (e.g. how many different models a client wishes to develop; the complexity of the models; and the number of groups involved) a modelling job can take between 2 and 15 workshops days. We utilise two facilitators per workshop group. These alternate between, on the one

hand, facilitating the group process as such and, on the other hand, tending the computer, recording and reflecting. Virtually all of the work is done in the workshop setting, with little back-office or software preparation time required. Also, the software is designed to facilitate project documentation during the workshop sessions themselves. The models which are generated during these sessions belong to the client, who is provided with software and documentation to run and maintain them.

The analysis phase begins by identifying and defining the most important dimensions of the problem complex to be investigated. Each of these dimensions is then given a range of relevant values or conditions. Together, these make up the variables or parameters of the problem to be structured. A morphological field is constructed by setting the parameters against each other, in parallel columns, representing an n-dimensional configuration space. A particular constructed “field configuration” (morphotype) is designated by selecting a single value from each of the variables. This marks out a particular state or (formal) solution within the problem complex (see Figure 1, above)

Ideally, one would examine all of the configurations in the field, in order to establish which of them are possible, viable, practical, interesting, etc., and which are not. In doing so, we mark out in the field a relevant “solution space”. The solution space of a Zwickian morphological field consists of the subset of configurations, which satisfy some criteria – one of which is *internal consistency*.

However, a typical morphological field of 6-10 variables can contain between 50,000 and 5,000,000 formal configurations, far too many to inspect 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 identifying, and weeding out, all mutually contradictory conditions.

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). 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

		The medium t				The type of m				Physical st			Type of thr		Type o	
		Vacuum	The atmosphere	Large bodies of water	The interior of earth	Rest	Translatory	Oscillatory	Rotatory	Gaseous	Liquid	Solid	None	Internal	External	Self igniting
The type of motion of the propellant relative to the jet engine	Rest															
	Translatory															
	Oscillatory															
	Rotatory															
Physical state of propellant	Gaseous															
	Liquid															
	Solid															
Type of thrust augmentation	None															
	Internal															
	External															
Type of ignition	Self igniting															
	External ignition															
Sequence of operations	Continuous															
	Intermittent															

Figure 2 Cross-consistency matrix for the propulsive system morphology in Figure 1.

direction or causality, but only to mutual consistency. Using this technique, a typical morphological field can be reduced by up to 90 or even 99%, depending on the problem structure. (Scenario fields are an exception, as will be discussed below.)

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 to be highly improbable or implausible on empirical grounds). Normative constraints can also be applied, although these must be used with great care, and clearly designated as such.

This technique of using pair-wise consistency relationships between conditions, in order to weed out internally inconsistent configurations, is made possible by a principle of dimensionality inherent in the morphological approach. While the number of configurations in a morphological field grows exponentially with each new parameter, the number of pair-wise relationships between conditions grows only as a quadratic polynomial – more specifically, in proportion to the triangular number series. Naturally,

there are practical limits reached even with quadratic growth. However, a morphological field involving 100,000 formal configurations can require no more than few hundred pair-wise evaluations in order to create a solution space.

When this solution (or outcome) space is synthesized, the resultant morphological field becomes an inference model, in which any parameter (or multiple parameters) can be selected as "input", and any others as "output". Thus, with computer support, the field can be turned into a laboratory with which one can designate initial conditions and examine alternative solutions.

GMA seeks to be integrative and to help discover new relationships or configurations. Importantly, it encourages the identification and investigation of boundary conditions, i.e. the limits and extremes of different parameters within the problem space. The method 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 immedi-

ately (and embarrassingly) evident when they are cross-referenced and assessed for internal consistency. Like most PSMs dealing with *wicked problems* and *social messes*, GMA requires strong, experienced facilitation, an engaged group of subject specialists and a good deal of patience.

Structuring complex social planning problems with GMA

GMA is especially suitable for pitting strategies against scenarios. (Note: In the text below, we use the term *scenario* in the sense of a future “situation” or “projection”, and not as a series of developments.) In such cases, two complementary morphological fields are developed: one for generating different possible futures projections based on factors that cannot be directly controlled (an “external world” field or *contextual environment*); and one for modelling strategy or system variables, which can – more or less – be controlled (an “internal world” field or *strategy space*). These two fields can then be linked by cross-consistency assessments in order to establish which strategies would be most effective and/or flexible for different ranges of futures projections.

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 (Ritchey & Stenström, 2004).

Extended producer responsibility (EPR) imposes accountability over the entire life cycle of products and packaging introduced on the market. This means that firms, which manufacture, import and/or sell products and packaging, are required to be financially or physically responsible for such products after their useful life. They must either take back spent products and manage them through reuse, recycling or in energy production, or delegate this responsibility to a third party, a so-called producer responsibility organization (PRO), which is paid by the producer for spent-product management. In this way, EPR shifts responsibility for waste from government to private industry, obliging producers, importers and/or sellers to internalise waste management costs in their product prices (Hanisch, 2000).

The long-term purpose of EPR is to encourage more environmentally friendly product development – products that require fewer resources, are easier to reuse/recycle, and which contain fewer environmentally dangerous substances. The problem, then, is to develop flexible EPR-strategies for a future in which there is a good deal of uncertainty concerning, for instance, national and international directives, technological developments, shifting political ideologies, market forces and ethical concerns.

The purpose of the EPR study was to systematically formulate a range of future *contextual environments* by which to test alternative EPR strategies. Two working groups of seven persons each – a “strategic environment group” and a “strategy development group” – performed the modelling together with two morphologists from FOI. The groups were composed of researchers from the Swedish EPA and other relevant government authorities, from two NGOs and from two private companies involved in waste management and recycling. Each group worked two days on their respective fields, with a final one day joint session where the strategic environment model was merged with the strategy model.

Figure 3 is an EPR *scenario field* consisting of eight parameters which represent “external” factors that can influence or constrain a Swedish EPR system. The eight parameters generate 20,736 formal configurations. In contrast to strategy fields, or fields representing system solutions, scenario fields are often difficult to assess internally and reduce. This is because it is risky to exclude relationships which may seem improbable today, but which might very well be the case in five, ten or fifty years. In such cases, it is better to work backwards, so to speak: Select one or more parameters as drivers, choose a number of configurations based on varying these drivers, and then assess the chosen configurations for internal consistency. Repeat this process until the desired number of scenario projections is achieved.

For the study in question, eight *specific configurations* were chosen. Together, these covered all of the parameter states in the scenario field (“full field coverage”), and represented a broad range of futures projections. The configurations were then named and linked to the column at the far left, a scenario-name “placeholder”.

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 list of scenario configurations defined in the study. One configuration – *Current policies (Negative trend)* – is selected (grey).

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 – one possible strategy highlighted.

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 the field *specified*. When no such placeholder is present, then the field is *open*.)

Note: On the computer, morphological field configurations are colour-coded. For instance, selected input conditions are rendered in red, and output conditions in blue. In the figures below, red is represented by grey, and blue is represented by black.

Figure 4 is a *strategy field* which also (purely coincidentally) contains 8 parameters. It represents important “internal factors” of a (future) Swedish EPR system. The field generates 34,560 formal (strategy) configurations. A cross-consistency assessment reduced this to 480 strategies which were deemed realistic. An explicate strategy placeholder parameter 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 the viability of different strategies against chosen futures projections. 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. Although there are no purely technical constraints to working with such a large field, it produces an intimidatingly large cross-consistency matrix. Fortunately, we can get around this problem by using a condensed form of the scenarios: we simply merge the scenario “placeholder” parameter with the strategy field, as shown in Figure 5 (below).

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 configuration 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.

The *thorough method* assesses the relationships between the internal states of each (defined) scenario configuration, 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).

In working with linked morphological fields, there are no automatically designated independent variables or drivers. 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 allow chosen states within a proposed strategy to designate relevant scenarios.

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) scenario configurations 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.

As is the case with most other problem structuring methods, it is not the morphological model *as an end-product* which is the sole important result of a morphological analysis. Much of the utility of the morphological structuring process *is the process itself*. One of the implicit outcomes is a shared terminology and problem concept among participants, and a better understanding of wider contexts.

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. One scenario is selected (grey), with one of its possible strategy configurations shown (black).

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 6 Three strategy conditions selected (grey) in order to examine which other strategy conditions are compatible (black), and which scenarios these best match (black in far-left “scenario” parameter).

Conclusions

Different forms of PSMs have been developed in order to tackle the difficult methodological issues inherent in complex socio-technical planning problems. Following Rosenhead (1996), these methods should:

- accommodate multiple alternative perspectives rather than prescribe single solutions
- function through group interaction and iteration rather than back office calculations
- generate ownership of the problem formulation through transparency
- facilitate a graphical (visual) representation for the systematic, group exploration of a solution space
- focus on relationships between discrete alternatives rather than continuous variables
- concentrate on possibility rather than probability.

Computer-aided morphological analysis is fully attuned to these criteria and can be seen as an important complement to other PSMs employing hierarchic structures and causally directed relationships. The advantage of GMA as a problem structuring method is that it defines an actual (internally specified) parameter space in which different inputs can be given, alternative outputs obtained, and inferences (“what-if” assertions) made. Thus, in addition to being an elementary PSM, GMA is also compatible with more advanced modelling methods, and can be employed as a test-bed or first step in the development of other types of models – for instance, Bayesian Belief Networks and multi-criteria decision support models.

As is the case with all problem structuring methods and models, the output of a morphological analysis is no better than the quality of its input. However, even here the morphological approach has some advantages. It expressly provides for a good deal of in-built “garbage detection”, since poorly defined parameters 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. This type of garbage detection is extremely important when working with *wicked problems* and *social messes*.

References

- Ackoff, R. (1974). *Redesigning the Future*. Wiley: New York.
- Akao, Y. (ed.) (1990). *Quality Function Deployment: Integrating Customer Requirements into Product Design*. Cambridge, MA: Productivity Press.
- Ayres, R. U. (1969). *Morphological Analysis. Technological Forecasting and Long-range Planning*. McGraw-Hill: New York, pp. 72-93.
- Bailey, K. (1994). *Typologies and Taxonomies - An Introduction to Classification Techniques*, Sage University Papers: Sage Publications: Thousand Oaks, Baltimore.
- Bateson, W. (1896). *Materials for the study of variation*. Johns Hopkins University Press.
- Checkland, P. B. (1989). Soft Systems Methodology, In: J. Rosenhead, (ed.). *Rational Analysis for a Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict*. John Wiley & Sons: Chichester. 71-100.
- Cohen, L. (1995). *Quality function deployment: how to make QFD work for you*. Addison-Wesley Publishing Company, Massachusetts, USA.
- Coyle, R. (2004). *Practical Strategy: Structured Tools and Techniques*. Pearson Education: London.
- Coyle, R., Crawshay, R and Sutton, L. (1994). Futures Assessments by Field Anomaly Relaxation. *Futures* **26** (1):25-43.
- Dilthey, W. (1989) [1883]. *Introduction to the Human Sciences*. Princeton University Press: Princeton.
- Doty, D & Glick, W. (1994). Typologies as a Unique Form of Theory Building. *Acad Manage Rev*, **19**(2).
- Eden, C. (1989). Using Cognitive mapping for strategic options development and analysis (SODA). In: J. Rosenhead, (ed.). *Rational Analysis for a Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict*. John Wiley & Sons: Chichester. 21-42.
- Friend, J. (1989). The strategic choice approach. In: J. Rosenhead, (ed.). *Rational Analysis for a Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict*. John Wiley & Sons: Chichester. 71-100.
- Hanisch, C. (2000). Is Extended Producer Responsibility Effective?. *Environ Sci Technol*, **34** (7), pp.170A-175 A
- McGhee, G. R. (1999). *Theoretical Morphology: the concept and its applications*. Columbia University Press: New York.
- Müller-Merbach, H. (1975). The Use of Morphological Techniques for OR-Approaches to Problems, in Haley K B (ed.) (1976). *Operational Research '75*, North Holland Publishing Company.

- Norris, K. W. (1963). The Morphological Approach to Engineering Design. In: Jones, J. C. and Thornley, D. G. (eds.) *Conference on Design Methods*, Pergamon Press, Inc: Elmsford, pp. 115-140.
- 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. *Technol Forecast Soc* **19**: 331-360.
- Rhyne R. (1995^a). *Evaluating Alternative Indonesian Sea-Sovereignty Systems*. Informs: Institute for Operations Research and the Management Sciences.
- Rhyne, R. (1995^b). Field Anomaly Relaxation - The Arts of Usage, *Futures* **27** (6): 657-674.
- Ritchey, T. (1991). Analysis and Synthesis - On Scientific Method based on a Study by Bernhard Riemann. *Syst Res* **8**(4):21-41. (Revised 1996) [Online]. Available from the World Wide Web: www.swemorph.com/pdf/anaeng-r.pdf.
- Ritchey, T. (2003). *MA/Casper. Computer Support for Morphological Analysis: A Short Description*. [Online] Available from the World Wide Web: www.swemorph.com/pdf/macasper1.pdf.
- Ritchey, T. & Stenström, M. (2004). *Scenarios and Strategies for Extended Producer Responsibility: Using Morphological Analysis to Evaluate EPR System Strategies in Sweden*. (English Summary of a Swedish Government Report.) [Online]. Available from the World Wide Web: www.swemorph.com/downloads.html.
- Rittel, H. & Webber, M. (1973). Dilemmas in a General Theory of Planning. *Policy Sci* **4**:155-169.
- Rosenhead, J. (ed.) (1989). *Rational Analysis for a Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict*. John Wiley & Sons: Chichester.
- Rosenhead, J. (1996). What's the problem? An introduction to problem structuring methods. In: *Interfaces* **26**(6):117-131.
- Taylor, T. (1967). Preliminary Survey on Non-national Nuclear Threats. *Stanford Research Institute Technical Note SSC-TN-5205-83*, Sept. 17, 1967.
- Thompson, D'Arcy (1917). *On growth and form*. Cambridge University Press: Cambridge.
- Weber, M. (1949). *The Methodology of the Social Sciences*. Translated and edited by Shils, E. A. & Finch, H. A. The Free Press: New York.
- Zwicky, F. (1947). Morphology and Nomenclature of Jet Engines. *Aeronaut Eng Rev* **6**(6):49-50.
- Zwicky, F. (1948^a). Morphological Astronomy. *Observatory* **68**(845): 121-143.
- Zwicky, F. (1948^b). The Morphological Method of Analysis and Construction. In: *Courant Anniversary Volume*. Intersciences Publishers: New York, pp 461-470.
- Zwicky, F. (1969). *Discovery, Invention, Research - Through the Morphological Approach*. The Macmillan Company: Toronto.