Adapted from the paper "Fritz Zwicky, Morphologie and Policy Analysis", presented at the 16th EURO Conference on Operational Analysis, Brussels, 1998. ©Tom Ritchey, 2002- 2006.

General Morphological Analysis
A general method for non-quantified modelling

Tom Ritchey

ritchey@swemorph.com

Fritz Zwicky pioneered the development of morphological analysis (MA) as a method for investigating the totality of relationships contained in multi-dimensional, usually non-quantifiable problem complexes. During the past two decades, MA has been extended and applied in the area of futures studies and for structuring and analysing complex policy spaces. This article outlines the fundamentals of the morphological approach and describes recent applications in policy analysis.

Keywords - methodology; morphology; morphological analysis, typologies, Zwicky, analysis and synthesis, non-quantified modelling, non-causal modelling, policy analysis, policy space

> *"... within the final and true world image everything is related to everything, and nothing can be discarded a priori as being unimportant." (Fritz Zwicky: Discovery, Invention, Research through the Morphological Approach.)*

INTRODUCTION

General Morphological analysis (MA) was developed by Fritz Zwicky - the Swiss-American astrophysicist and aerospace scientist based at the California Institute of Technology (CalTech) - as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes (Zwicky 1966, 1969).

Zwicky applied this method to such diverse fields as the classification of astrophysical objects, the development of jet and rocket propulsion systems, and the legal aspects of space travel and colonization. He founded the Society for Morphological Research and advanced the "morphological approach" for some 40 years, between the early 1930's until his death in 1974.

More recently, morphological analysis has been applied by a number of researchers in the USA and Europe in the fields of policy analysis and futures studies (e g Rhyne 1981, 1995a, 1995b; Coyle 1994, 1995, 1996). In 1995, advanced computer support for MA was developed at the Swedish Defence Research Agency (for a description, see Ritchey, 2003b). This has made it possible to create non-quantified inference models, which significantly extends MA's functionality and areas of application (Ritchey 1997, 1998, 2002, 2003a, 2004, 2005a, 2005b, 2006a, 2006b). Since then, some 80 projects have been carried out using computer aided morphological analysis, for structuring complex policy and planning issues, developing scenario and strategy laboratories, and analyzing organizational and stakeholder structures.

This article will begin with a discussion of some of the methodological problems confronting complex, non-quantified modelling, especially as applied to policy analysis and futures studies. This is followed by a presentation of the fundamentals of the morphological approach along with a recent application to policy analysis.

METHODOLOGICAL BACKGROUND

Analysing complex policy fields and developing futures scenarios presents us with a number of difficult methodological problems. Firstly, many, if not all of the factors involved are non-quantifiable, since they contain strong social-political dimensions and conscious self-reference among actors. This means that traditional quantitative methods, causal modelling and simulation are relatively useless.

Secondly, the uncertainties inherent in such problem complexes are in principle non-reducible, and often cannot be fully described or delineated. This represents even a greater blow to the idea of causal modelling and simulation.

Finally, the actual process by which conclusions are drawn in such studies 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.

An alternative to formal (mathematical) methods and causal modelling is a form of non-quantified modelling relying on *judgmental processes* and *internal consistency*, rather than causality. Causal modelling, when applicable, can – and should – be used as an aid to judgement. However, at a certain level of complexity (e.g. at the social, political and cognitive level), judgement must often be used -- and worked with -- more or less directly. The question is: How can judgmental processes be put on a sound methodological basis?

Historically, scientific knowledge develops through cycles of analysis and synthesis: every synthesis is built upon the results of a proceeding analysis, and every analysis requires a subsequent synthesis in order to verify and correct its results (Ritchey, 1991). However, analysis and synthesis – as basic scientific methods – say nothing about a problem having to be quantifiable.

Complex social-political problem fields can be analysed into any number of non-quantified variables and ranges of conditions. Similarly, sets of non-quantified conditions can be synthesised into well-defined relationships or configurations, which represent "solution spaces". In this context, there is no fundamental difference between quantified and non-quantified modelling.

Morphological analysis – extended by the technique of *cross consistency assessment* (CCA) – is a method for rigorously structuring and investigating the internal properties of inherently non-quantifiable problem complexes, which contain any number of disparate parameters. It encourages the investigation of boundary conditions and it virtually compels practitioners to examine numbers of contrasting configurations and policy solutions. Finally, although judgmental processes may never be fully traceable in the way, for example, a mathematician formally derives a proof, MA does go a long way in providing as good an audit trail as one can hope for.

THE MORPHOLOGICAL APPROACH

The term *morphology* comes from classical Greek (*morphe*) and means the study of **shape** or **form**. It is concerned with the structure and arrangement of parts of an object, and how these *conform* (i.e. fit together) to create a whole or Gestalt. The "objects" in question can be physical (e.g. an organism, an anatomy or an ecology), social (e.g. an organisation or stakeholder structure) or mental (e.g. linguistic forms, concepts or systems of ideas).

The first to use the term *morphology* as an explicitly defined scientific method would seem to be J.W. von Goethe (1749-1832), especially in his "comparative morphology" in botany. Today, morphology is associated with a number of scientific disciplines. In linguistics, morphology is the study of word formation and how the parts of words relate to each other. Morphology is used in disciplines where *formal structure*, and not necessarily quantity, is a central issue, e.g. geology, anatomy, zoology etc.

Fritz Zwicky proposed a *generalised form of morphological research*:

> ”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, 1966, p. 34)

Essentially, general morphological analysis is a method for identifying and investigating the total set of possible relationships or “configurations” contained in a given problem complex. In this sense, it is closely related to typology construction (Bailey 1994), although it is more generalised in form and conceptual range.

The approach begins by identifying and defining the parameters (or dimensions) of the problem complex to be investigated, and assigning each parameter a range of relevant “values” or conditions. A morphological box – also fittingly known as a “Zwicky box” – is constructed by setting the parameters against each other in an n-dimensional matrix (see Figure 1, below). Each cell of the n-dimensional box contains one particular ”value” or condition from *each* of the parameters, and thus marks out a particular state or configuration of the problem complex.

For example, imagine a simple problem complex, which we define as consisting of three dimensions – let us say ”colour”, ”texture” and ”size”. In order to conform to Figure 1, let us further define the first two dimensions as consisting of 5 discrete ”values” or conditions each (e.g. colour = red, green, blue, yellow, brown) and the third consisting of 3 values (size = large, medium, small) . We then have 5·5·3 (= 75) cells in the Zwicky box, each containing 3 conditions – i.e. one from each dimension (e.g. red, rough, large). The entire 3-dimensional matrix is, in Zwicky’s terms, a morphological field containing all of the (formally) possible relationships involved. This is what he refers to as ”complete, systematic field coverage”.

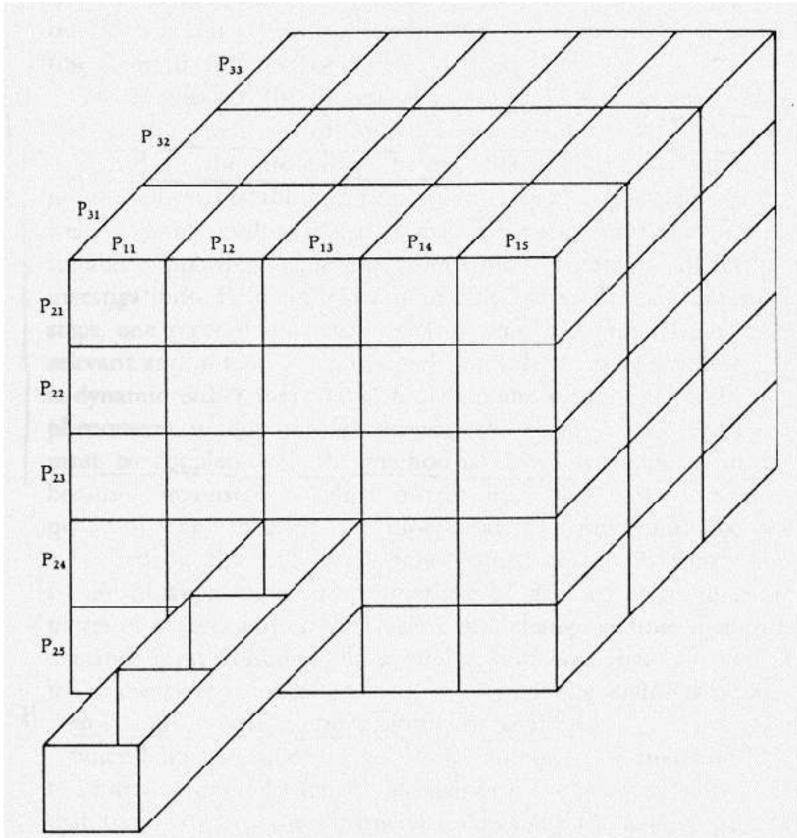


Figure 1: A 3-parameter Zwicky box containing 75 cells or ”configurations” (Zwicky, 1969, p. 118.)

The point is, to 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 this, we mark out in the field what might be called a ”solution space. The ”solution space” of a Zwickian morphological field consists of the subset of configurations, which satisfy some criteria.

Of course, the matrixing of parameters, in order to uncover the multiplicity of relationships associated with a problem complex, is nothing new. The virtually universal use of ”four-fold tables” and the study of typology construction as a classification technique attests to this fact (Bailey, 1994). However, Zwicky’s highly systematic approach to this field should not be underestimated. The method seeks both to be integrative and to explore the boundary conditions of complex problems. Used properly – and on the right types of problem complexes – the method is deceptively complex and rich.

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 may help us to 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 factors.

It 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 parameters become immediately (and embarrassingly) evident when they are cross-referenced and assessed for internal consistency (see below).

One apprehension that has been voiced against MA is that it is *too* structured – too much German *Grundligheit* – and that this risks inhibiting free, creative thinking. Zwicky would turn in his grave. For him, the whole point of morphological analysis and systematic "complete field coverage" is to get us "out of the box", to push consciousness to the limits of the conceivable and to facilitate discovery, not to obstruct it. Properly applied, general morphological analysis offers an excellent balance between freedom and (necessary) constraints.

Also, computer-aided morphological analysis is a pre-eminent method for structuring and modelling what are variously called *wicked problems* and *social messes* (Ritchey, 2005a). These are complex, long-term societal and organisational planning problems which are continually evolving in a dynamic social context.

Two simple examples of morphological analysis may suffice to illustrate the principles of the method. The first of these is an example which Zwicky himself presents in his cited book. As a preparatory step in the investigation of new propulsive systems, Zwicky matrixed a list of "energy forms" against itself in order to examine every possible form of energy conversion.

Suppose we wanted to investigate such conversions in three steps instead of two (in this example I have shortened the list of "energy forms" to five.)

This particular matrix (next page) involves 5^3 (=125) possible configurations, each of which can be examined from the point of view of possibility, practicability, effectiveness, applications, or whatever criteria are relevant for the problem at hand. (Note that this matrix is simply a transformation of the 3-dimensional Zwicky box in Figure 1. The marked configuration K->E->C, for instance, represents a single cell in the box.)

Initial Energy Form	Transmission Form	Final (Storage) Form
(K) Kinetic	(K) Kinetic	(K) Kinetic
(E) Electrical	(E) Electrical	(E) Electrical
(C) Chemical	(C) Chemical	(C) Chemical
(T) Thermal	(T) Thermal	(T) Thermal
(N) Nuclear	(N) Nuclear	(N) Nuclear

Figure 2: Energy Conversion Matrix (example)

For example, K->E->C can represent hydroelectric generation which is then stored in a battery. C->T->K could represent an internal combustion engine (chemical energy transformed into thermal energy) leading to energy being stored in a flywheel. E->C->T represents a refrigerator.

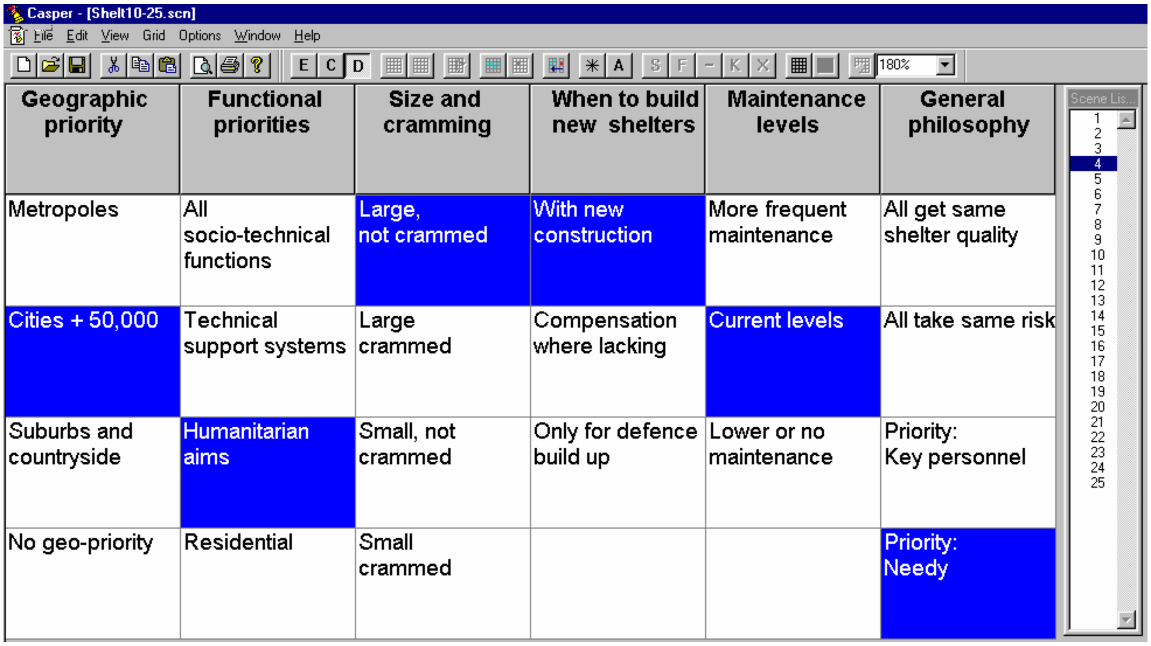
Even this simple example is surprisingly complex. Zwicky examined single conversions for 10 different "energy forms" in a 2-dimensional matrix. Try it – and you will be surprised about how much you learn about energy.

A second example is drawn from work that my organization – the Swedish National Defence Research Agency (FOI) – has done concerning the future of the Swedish bomb shelter program. During the Cold War period, Sweden invested large sums of money annually in the planning, building and maintenance of these shelters. With the end of the cold war, the shelter program – its form, usefulness and expense – came under greater scrutiny. This problem, which has aspects of both policy analysis and a futures study, is eminently suited for morphological analysis.

The first problem was to identify and properly define the dimensions of the problem – that is to say, the relevant *issues* involved. These include technical, financial, political and ethical issues. One of the advantages of MA is that there are no formal constraints to mixing and comparing such different types of issues. On the contrary, if we are really to get to the bottom of the policy problem, we must treat all relevant issues *together*.

Secondly, for each issue (parameter), a spectrum of "values" must be defined. These values represent the possible, relevant conditions that each issue can assume. For instance, if one of the relevant issues is shelter size, then we can – with the proper expert group present or consulting from a distance – determine all possible size differentiations. (In the somewhat simplified example below, we distinguish only between *small* and *large*. Note that this column in fact consists of a four-fold table, where we have combined two binary relationships – size and degree of cramming – into a single parameter.) A portion of one of the policy spaces, which were developed for this study, is presented in Figure 3, below. It has been reduced from its original ten parameters to six.

This segment of the shelter matrix contains 2304 possible configurations, one of which is shown in the figure. (The number of possible configurations is the product of the number of conditions under each parameter: 4x4x4x3x3x4). It is fairly easy – by hand – to identify and mark out a few dozen realistic policy configurations. Examining *all* possible configurations, however, would take a good deal more time and effort. Furthermore, the original 10-dimensional shelter matrix contained more than 300,000 possible configurations – far too many to deal with by hand.



Geographic priority	Functional priorities	Size and cramming	When to build new shelters	Maintenance levels	General philosophy
Metropoles	All socio-technical functions	Large, not crammed	With new construction	More frequent maintenance	All get same shelter quality
Cities + 50,000	Technical support systems	Large crammed	Compensation where lacking	Current levels	All take same risk
Suburbs and countryside	Humanitarian aims	Small, not crammed	Only for defence build up	Lower or no maintenance	Priority: Key personnel
No geo-priority	Residential	Small crammed			Priority: Needy

Figure 3: Segment of morphological field for the Swedish bomb shelter program study, showing one of 25 possible policy solutions.

ANALYSIS AND SYNTHESIS OF COMPLEX POLICY SPACES

The next step in the analysis-synthesis process is to reduce the total set of (formally) possible configurations in a morphological field to a smaller set of internally consistent configurations representing a ”solution space”. This is what Zwicky called his *principle of contradiction and reduction*. As a procedure, I will refer to this as the process of “cross-consistency assessment” (CCA).

CCA is based upon the insight that there may be numerous pairs of conditions in the morphological field which are mutually inconsistent or contradictory. For instance, in the Shelter Program matrix (Figure 3), the condition ”All (citizens) take the same risk” is incompatible with that of ”No geographical priority” – if it is assumed that an adversary would, indeed, make geographical priorities by concentrating on bombing larger cities. Similarly, the shelter philosophy of “All get same shelter quality” is not consistent with any form of geographical priority.

Thus not all combinations of conditions are consistent or compatible. To the extent that a particular pair of conditions is a blatant contradiction, *then all those configurations containing this pair of conditions would also be internally inconsistent*.

To make a cross-consistency assessment, all of the parameter values (conditions) in the morphological field are compared with one another, pair-wise, in the manner of a cross-impact matrix (see Figure 4, below). As each pair of conditions is examined, a judgement 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 consistency.

There are three types of inconsistencies involved here: purely logical contradictions (i.e. those based on the nature of the concepts involved); empirical constraints (i.e. relationships judged be highly improbable or implausible on empirical grounds), and normative constraints (e.g. relationships ruled out on e.g. ethical or political grounds).

Note, that it is extremely important *not* to allow normative judgments to initially influence the cross-consistency assessment. For this reason, we only allow logical and empirical judgements to be made initially. Although normative judgements must be made eventually, they must never be *confused* with logical and empirical consideration. We must first discover what we judge as possible, before we make judgements about what is desirable.

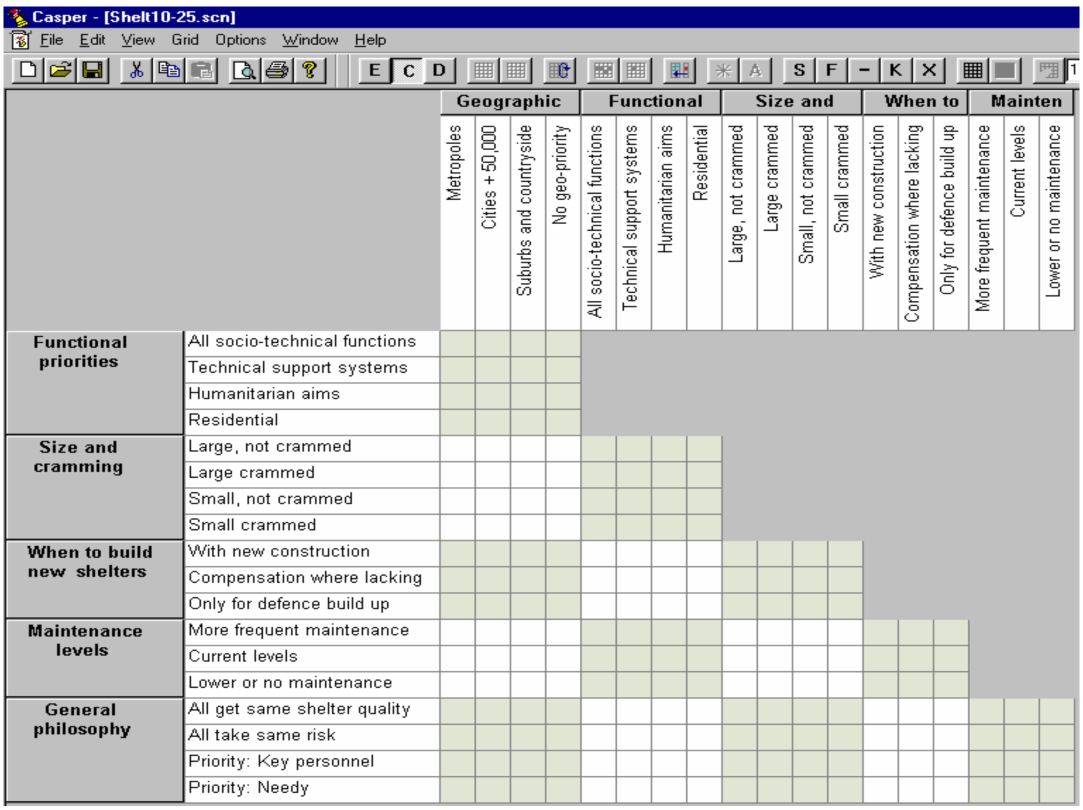


Figure 4: Cross-consistency matrix

This technique, of using pair-wise consistency relationships between conditions to weed out internally inconsistent configurations, is made possible by a principle of dimensionally 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 -- or, more specifically, proportional to 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 a few hundred pair-wise evaluations in order to create a solution space.

In most of the fields that we have worked with it is usually the case that 90% or more of the configurations are ”relaxed”, i.e. they fall out of the running because they contain some sort of internal contradiction. (Long-term "future scenario"-fields are an exception, because empirical constrains are difficult to establish.)

This allows one to concentrate on a manageable number of internally consistent configurations. These can then be examined as elements of scenarios or specific solutions in a complex policy space. (For this purpose, FOA has developed a Windows-based software package which supports the entire analysis-synthesis process which General Morphology entails. The program is called MA/*Casper*: Computer Aided Scenario and Problem Evaluation Routine.)

CONCLUSIONS

Morphological analysis, including the process of ”cross-consistency assessment”, is based on the fundamental scientific method of alternating between analysis and synthesis. For this reason, it can be trusted as a useful, non-quantified method for investigating problem complexes, which cannot be treated by formal mathematical methods, causal modelling and simulation.

Furthermore, both the morphological field itself, and the assessments put into the cross-consistency matrix, represent a fairly clear “audit trail”, which makes the judgmental processes inherent in MA relatively traceable, and – in a certain sense – even reproducible. We have run trials in which identical morphological fields were presented to different groups for cross-consistency assessment. Comparing the results, and bringing the groups together to discuss diverging assessments, helps us to better understand the nature of the policy issues involved, and also tell us something about the effects of group composition on the assessments.

Of course, as is the case with everything else, 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 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. This type of garbage detection is something that policy analyses and futures studies certainly need more of.

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