General Morphological Analysis*
A general method for non-quantified modelling

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Fritz Zwicky pioneered the development of General Morphological Analysis (GMA) as a method for investigating the totality of relationships contained in multi-dimensional, non-quantifiable problem complexes. During the past two decades, GMA has been computerised, extended and employed for structuring complex policy and planning issues, developing scenario and strategy laboratories, and analyzing organizational and stakeholder structures. This article outlines the fundamentals of the morphological approach and describes an application in policy analysis.

Keywords – general morphological analysis, morphological modelling, typology analysis, Fritz Zwicky, non-quantified modelling, policy analysis

> *"... 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 (GMA) was developed by Fritz Zwicky – the Swiss 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 30 years, between the 1940's until his death in 1974.

More recently, GMA has been applied by a number of researchers in the USA and Europe in the fields of policy analysis and futures studies (e.g. Godet, 1994; Rhyne 1995; Coyle & McGlone, 1995; Ritchey 1997). In 1995, advanced computer support for GMA was developed at the Swedish Defence Research Agency (for a description, see Ritchey, 2003b). This has made it possible to create interactive, non-quantified inference models, which significantly extends GMA's functionality and areas of application (Ritchey 1998-2011). Since then, more than 100 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.

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* Adapted from the paper "Fritz Zwicky, 'Morphologie' and Policy Analysis", presented at the 16th EURO Conference on Operational Analysis, Brussels, 1998. Contact: ritchey@swemorph.com

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, 2012). 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.

GENERAL MORPHOLOGY

The term *morphology* comes from antique Greek (*morphe*) and means *shape* or *form*. The general definition of morphology is "the study of form or pattern", i.e. the shape and arrangement of parts of an object, and how these "conform" to create a *whole* or Gestalt. The "objects" in question can be physical objects (e.g. an organism, a geography or an ecology), social objects (an organisation or other social system) or mental objects (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 which *formal structure*, and not primarily quantity, is a central issue. In linguistics, it is the study of word formation; in biology, it deals with the form and structure of organisms; in geology it concerns the characteristics, configuration and evolution of rocks and land forms.

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 analysis*, although GMA is more generalised in form and has far broader applications. (A brief history of morphological methods is presented in Ritchey, 2006a.)

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 1a). 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 1a, 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 5x5x3 (= 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 a *typological field* containing all of the (formally) possible relationships involved.

The *typological field format* utilizes the dimensions of physical space to represent its variables, as in a Cartesian coordinate system. 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.) Employing the *morphological field format* (Figure 1b) liberates us from the spatial constraints of 3-dimensional space, and allows us to allocate of any number of dimensions.

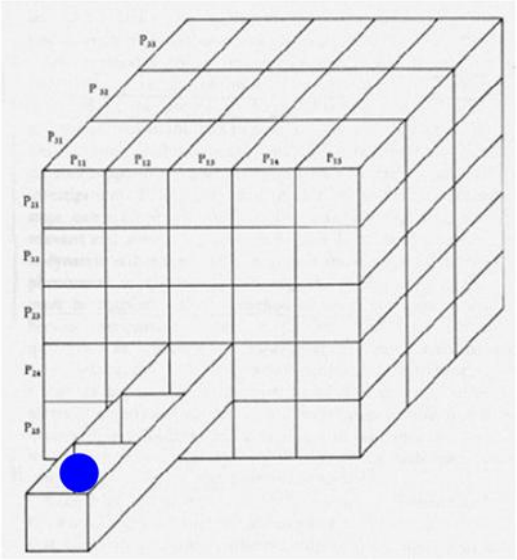
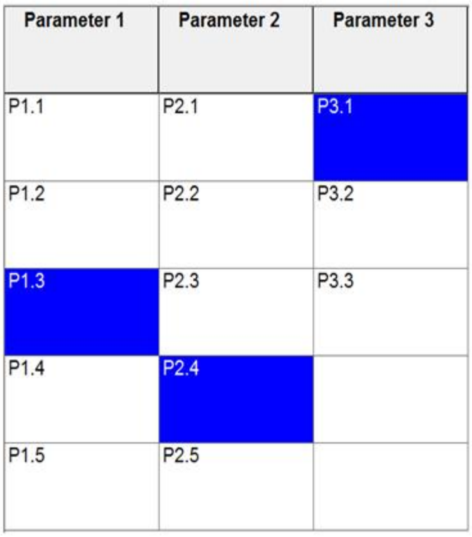


Figure 1a: 3-parameter "Zwicky Box" in typological format, containing 75 (5x5x3) cells (Zwicky, 1969).



Parameter 1	Parameter 2	Parameter 3
P1.1	P2.1	P3.1
P1.2	P2.2	P3.2
P1.3	P2.3	P3.3
P1.4	P2.4	
P1.5	P2.5	

Figure 1b: 3-parameter field in morphological format. (The blue configuration corresponds to the blue marked cell in Figure 1a.)

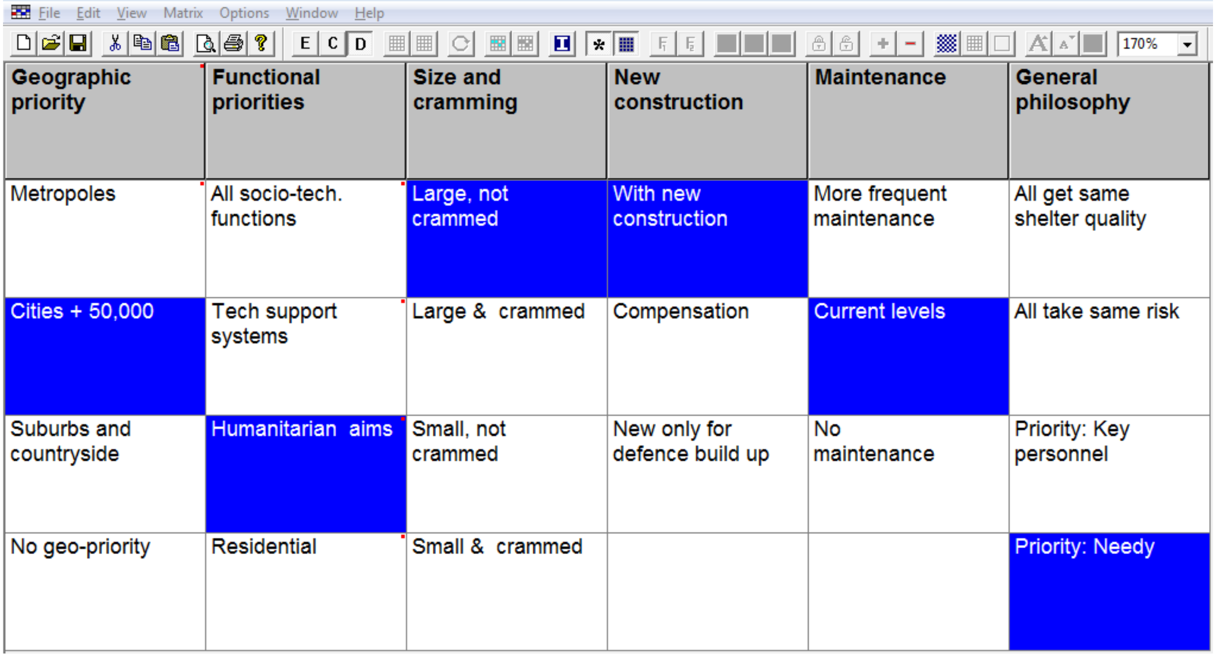
Of course, the "matrixing" of parameters, in order to uncover the multiplicity of relationships associated with a problem complex, is nothing new. The ubiquitous "four-fold table" and the study of typology construction as a classification technique attest to this fact (Bailey, 1994; Doty & Glick, 1994). However, Zwicky's highly systematic approach to multi-dimensional problem structuring turned general morphology into a discipline in itself. 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.

A simple example of morphological analysis may suffice to illustrate the principles of the method. This is drawn from work that the Swedish National Defence Research Agency (FOI) did 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 costs – 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 e.g. technical, financial, political and ethical issues. One of the advantages of GMA 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 possible, relevant states or conditions that each parameter can assume. A segment of one of the policy spaces, which was developed for this study, is presented in Figure 2. It has been reduced from its original ten parameters to six, and is used here only for pedagogical purposes.

This field 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 500,000 possible configurations – far too many to deal with by hand.



Geographic priority	Functional priorities	Size and cramming	New construction	Maintenance	General philosophy
Metropoles	All socio-tech. functions	Large, not crammed	With new construction	More frequent maintenance	All get same shelter quality
Cities + 50,000	Tech support systems	Large & crammed	Compensation	Current levels	All take same risk
Suburbs and countryside	Humanitarian aims	Small, not crammed	New only for defence build up	No maintenance	Priority: Key personnel
No geo-priority	Residential	Small & crammed			Priority: Needy

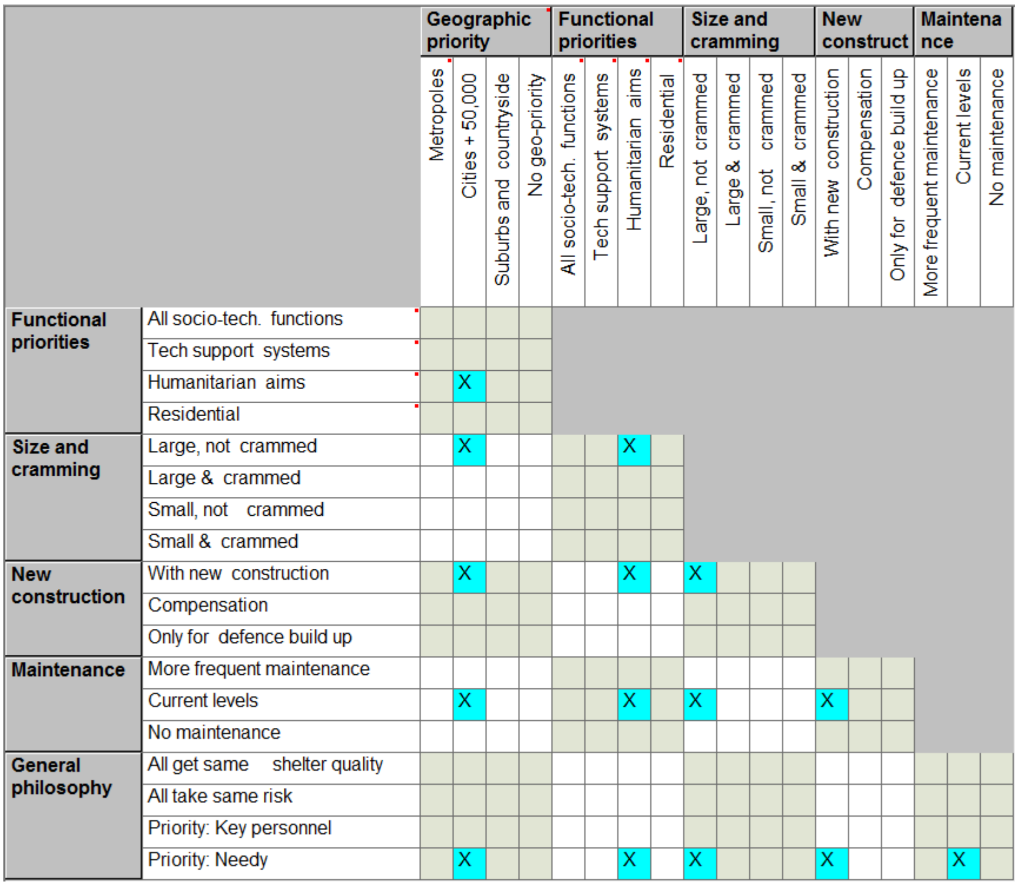
Figure 2: Segment of morphological field for the Swedish bomb shelter program study, with 2304 possible (formal) configurations – one shown.

CROSS-CONSISTENCY ASSESSMENT

The next step in the analysis-synthesis process is to reduce the total set of (formally) possible configurations in the problem space to a smaller set of *internally consistent* configurations representing a "solution space". This is what Zwicky called the *principle of contradiction and reduction*, and what we refer to 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 incompatible. For instance, in the Shelter Program matrix, the condition that "All get same shelter quality" is not consistent with any form of geographical priority. To the extent that a particular pair of conditions is incompatible, or indeed 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 (Figure 3). 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* or direction, but only to (mutual) consistency.



		Geographic priority				Functional priorities				Size and cramming				New construct			Maintenance		
		Metropoles	Cities + 50,000	Suburbs and countryside	No geo-priority	All socio-tech. functions	Tech support systems	Humanitarian aims	Residential	Large, not crammed	Large & crammed	Small, not crammed	Small & crammed	With new construction	Compensation	Only for defence build up	More frequent maintenance	Current levels	No maintenance
Functional priorities	All socio-tech. functions																		
	Tech support systems																		
	Humanitarian aims		X																
	Residential																		
Size and cramming	Large, not crammed		X					X											
	Large & crammed																		
	Small, not crammed																		
	Small & crammed																		
New construction	With new construction		X					X		X									
	Compensation																		
	Only for defence build up																		
Maintenance	More frequent maintenance																		
	Current levels		X					X		X				X					
	No maintenance																		
General philosophy	All get same shelter quality																		
	All take same risk																		
	Priority: Key personnel																		
	Priority: Needy		X					X		X				X				X	

Figure 3. Cross-consistency assessment (CCA) matrix showing the 15 pair relationships (X-marked) in Figure 2

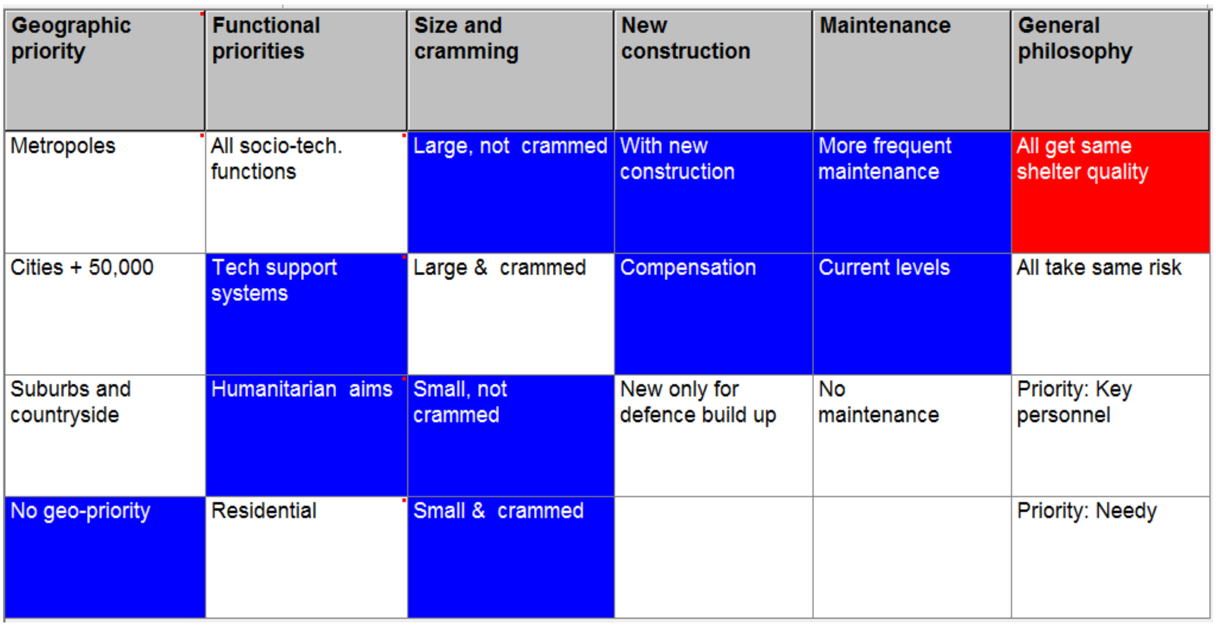
There are three types of inconsistencies involved here: purely *logical contradictions* (i.e. those based on the nature of the concepts involved); *empirical inconsistencies* (i.e. relationships judged to be highly improbable or implausible on empirical grounds), and *normative constraints* (e.g. relationships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

Note, however, that it is 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 can, and often must, be made, they must never be *confused* with logical and empirical consideration. We must first investigate what is *possible*, before making judgements about what is, and what is not, *desirable*.

This technique of using pair-wise consistency relationships between conditions, in order to weed out internally inconsistent configurations, is based on a principle of dimensionally inherent in the morphological approach. While the number of configurations in a morphological field grows exponentially (or “factorially”) 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. 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.

The CCA reduction allows us to concentrate on a manageable number of internally consistent configurations. With dedicated software, the internally constrained morphological field becomes an inference model or virtual laboratory, where one can designate inputs, define drivers, and examine resultant output configurations as elements of scenarios or strategies in a complex policy space.

Figure 4 shows a single driver input (red) and a clustered output. In this instance, we are essentially asking the model: "Given the policy decision that every person shall have the same shelter quality, what is the *option space* concerning the other parameters?" Figure 5 shows a multi-driver input (red) and corresponding clustered output.



Geographic priority	Functional priorities	Size and cramming	New construction	Maintenance	General philosophy
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Cities + 50,000	Tech support systems	Large & crammed	Compensation	Current levels	All take same risk
Suburbs and countryside	Humanitarian aims	Small, not crammed	New only for defence build up	No maintenance	Priority: Key personnel
No geo-priority	Residential	Small & crammed			Priority: Needy

Figure 4. Single parameter driver: All get same shelter quality

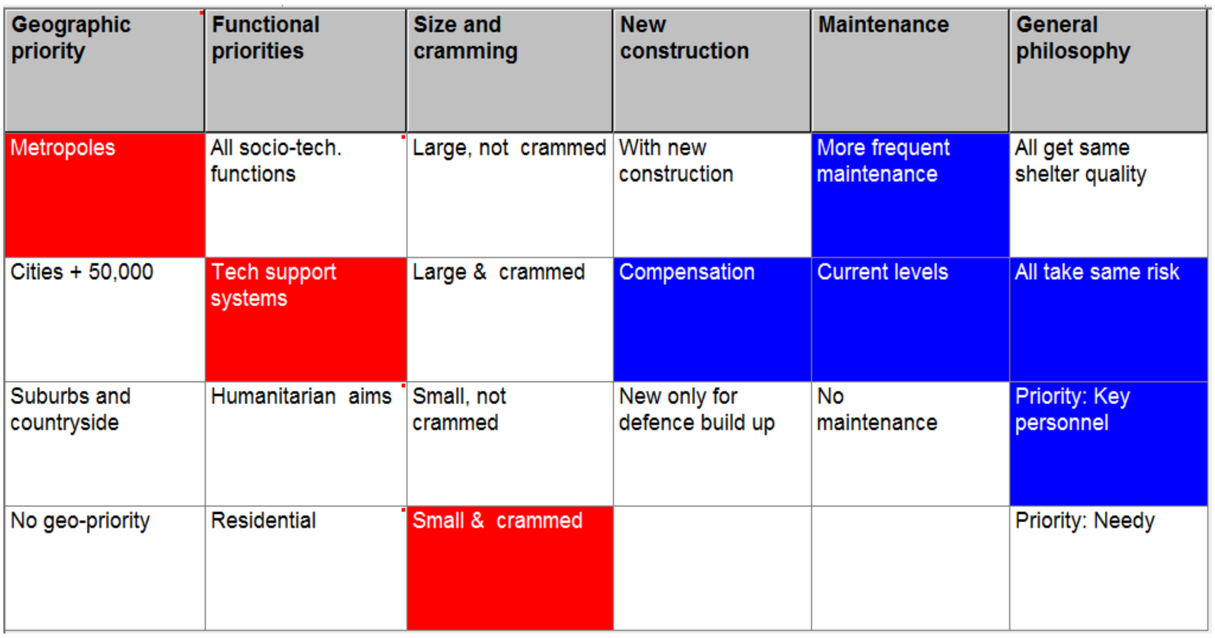

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Figure 5. Triple parameter driver.

CONCLUSIONS

General 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.

[For a comparison of GMA with seven other modeling methods employed in Operational Research and Management Science (OR/MS), see Ritchey, 2012*.]

Zwicky called the morphological approach "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 systematic – methods. Importantly, it encourages the identification and investigation of *boundary conditions*, i.e. the limits and extremes of different contexts and factors.

GMA 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. Such 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 is a form of *garbage detection* that policy analysis and futures studies certainly need more of.

Finally, 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 GMA 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 tells us something about the effects of group composition on the assessments.

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* "Outline for a Morphology of Modeling Methods: Contribution to a General Theory of Modelling", *Acta Morph Gen*, 2012. Available at http://www.amg.swemorph.com/pdf/amg-1-1-2012.pdf.)

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