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# Four Models about Decision Support Modeling

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**Abstract.** Models and modelling methods play an essential role in Operational Research and Management Science (OR/MS). This article presents four models which concern how OR/MS employs different modelling methods for different modelling tasks, under different constraints, and for different forms of uncertainty. Two of these "meta-models" concern how OR/MS modelling has been employed in decision support for the Swedish Defence Research Agency: one of them from a more academic or theoretical perspective, the other more from the perspective of the practitioner. The third model concentrates on how different modelling techniques are constrained by varying stakeholder positions. The final model is introspective and classifies a variety of modelling methods on the basis of a number of formal modelling properties. All of these meta-models were developed using the non-quantified modelling method General Morphological Analysis (GMA).

**Keywords:** Modelling theory, general morphological analysis; operational research, management science, decision science, decision support

## 1. Introduction

Operational Research and Management Science (OR/MS) is a broad, interdisciplinary field of combined research and practice which employs scientific methods in order to support decision making. Originally developed as an area of applied mathematics during World War II, it was used to aid military planning and operations and was predominantly quantitative. Today, however, OR/MS – a.k.a. *Decision Science* – employs both quantitative and non-quantitative (e.g. judgement-based) methods, and undertakes a number of associated tasks such as problem structuring, problem bounding, group decision support facilitation and, in general, the complete *decision support process*.

By its very nature, models and modelling play an essential role in OR/MS, as do the methodological issues underlying the very concept of modelling. And although OR/MS is certainly not unique in being interested in the issues and problems of its own methods and techniques (all science has a necessary epistemological "self-examination" aspect), it is arguably one of those disciplines which is most involved in, and I dare say in need of, explicit self-examination.

One of the perennial questions in OR/MS concerns the *applicability* of different modelling methods for different modelling tasks, and especially as concerns different types of uncertainty. In this context, one of the main issues of contention – which has led to an on-and-off squabble since the late 1960s – has been that of employing highly technical, mathematical modelling methods (e.g. System Dynamics modelling) to inherently *agonistic* processes (i.e. decisions and actions based on human judgments, motivations and self-reflection). Notable contributions to this debate were made in the 1970's by Horst Rittel [1] [2], and Russell Ackoff [3]. Among more recent contributions to the discussion are Mingers [4], Ritchey [5] and Georgiou [6].

This issue of *applicability* is both a theoretical and, naturally, a practical problem. It has always been the dream of OR/MS practitioners to have a comprehensive "tool-box" of methods, and some sort of *diagnostic procedure* by which to identify appropriate modelling techniques for different modelling tasks and modelling requirements. Also, as OR/MS support began to expand into the "softer" layers of society, it began to be questioned if "hard" OR techniques, developed out of the 1940's and 50's,

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were suitable for modelling complex policy driven problems. In this context, analysts also felt that they ought to be part of the *problem formulation* and *problem structuring* process, instead of simply being a *receiver* of pre-defined problems [7].

In the 1970s and 80's, this led to the development of so-called soft OR methods, Problem Structuring Methods (PSM) [8] and what has come to be called *multimethodology* or "mixed method research" [9]. In Information Science and Engineering Design Theory, it has been termed *multi-formalism* and *multi-paradigm* modelling [10]; and, in a wider context, *conceptual modelling* in general [11].

In the middle of the 1990's, when computer-aided General Morphological Analysis (GMA) was being developed at the Swedish Defence Research Agency (FOI) in Stockholm, I was asked if GMA could be utilised in "mixed method research", in order to model different types of OR modelling methods which are applicable to different modelling tasks. We thus started a "meta-modelling" initiative, the purpose being both to increase our own understanding and competence in dealing with "mixed method research", and to help us better communicate methodological issues with our clients.

This article presents – *in brief* – four morphological models dealing with different aspects of OR/MS modelling. For those not already acquainted with GMA, we begin with a short historical and theoretical background.

## 2. Background to General Morphology†

The term *morphology* derives from antique Greek (*morphê*) which means *shape* or *form*. Morphology is "the study of form or pattern", i.e. the arrangement and connectivity of parts of an object, and how these "conform" to represent a *whole* or Gestalt. The "objects" in question can be physical (e.g. an organism or an ecology), social/organizational (e.g. an institution or company), or mental (e.g. linguistic forms or any system of ideas).

In Europe, morphological methods were used as early as 1290s by the theologian-logician Ramon Llull (1232-1315) in his *Ars magna* ("The Ultimate General Art"). Gottfried Leibniz (1646-1715) later developed it into a more grounded method in his *Ars combinatoria*. However, 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 where *formal structure* is a central issue, for instance, in anatomy, linguistics, geology and zoology.

In the late 1940's, Fritz Zwicky, professor of astrophysics at the California Institute of Technology (Caltech) proposed a *generalized form of morphology*, which today goes under the name of General Morphological Analysis (GMA)

> "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) [12]

Zwicky developed GMA as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes [12]. He applied the method to

† For a more detailed presentation, see the JORS article:" Problem Structuring with Computer-Aided Morphological Analysis" (pdf) at: http://www.swemorph.com/pdf/psm-gma.pdf.

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 championed the "morphological approach" from the 1940's until his death in 1974.

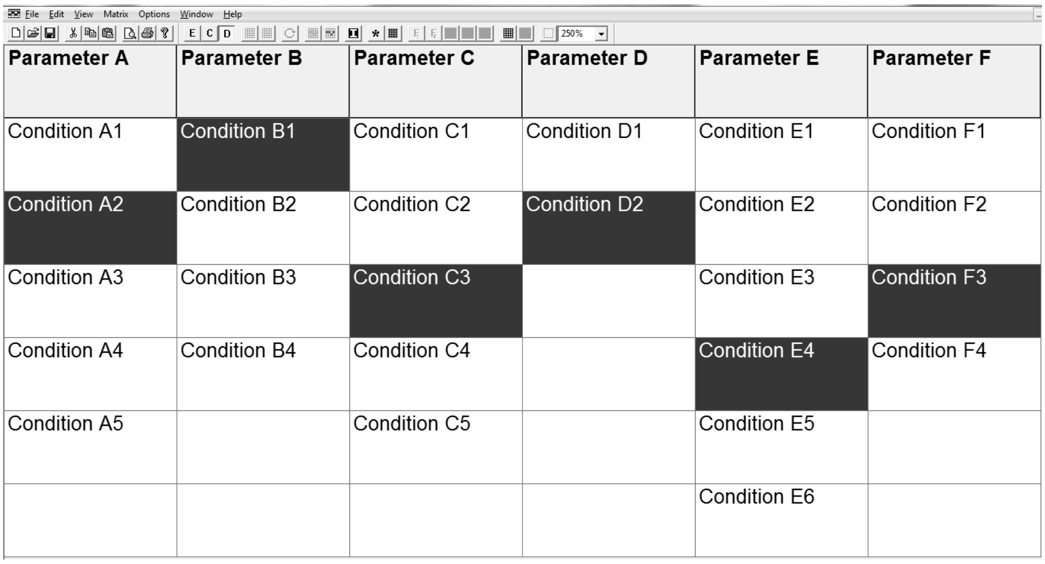
Morphological analysis was subsequently applied by a number of researchers in the USA and Europe in the fields of policy analysis and futures studies [13]. In1995, advanced computer support for GMA was developed at the Swedish Defence Research Agency (FOI) in Stockholm. This has made it possible to create non-quantified inference models, which significantly extends GMA's functionality and areas of application. Since then, some 100 projects have been carried out using GMA, for structuring complex policy and planning issues, developing scenario and strategy laboratories, and analyzing organizational and stakeholder structures [14].

Essentially, GMA is a method for identifying and investigating the total set of possible relationships contained in a given problem complex. This is accomplished by going through a number of iterative phases which represent cycles of analysis and synthesis – the basic method for developing (scientific) models [15].

The method begins by identifying and defining the most important *parameters* of the problem complex to be investigated, and assigning each parameter a range of relevant *values* or *conditions*. This is done mainly in natural language, although abstract labels and scales can be utilized to specify the set of elements defining the discrete *value range* of a parameter. (Note that we are using the term *parameter* not in its formal mathematical sense, but in its more general, systems science meaning: i.e. one of a number of factors that define a system and determine its behaviour, and which can be varied in an experiment, including a *Gedankenexperiment*).

A morphological field is constructed by setting the parameters against each other in order to create an n-dimensional configuration space (Figure 1). A particular *configuration* (the black cells in the matrix) within this space contains one ”value” from *each* of the parameters, and thus marks out a particular state of, or possible formal solution to, the problem complex.

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 a relevant *solution space*. The solution space of a Zwickian morphological field consists of the subset of all the possible configurations which satisfy some criteria. The primary criterion is that of *internal consistency*.



| Parameter A | Parameter B | Parameter C | Parameter D | Parameter E | Parameter F |
|---|---|---|---|---|---|
| Condition A1 | Condition B1 | Condition C1 | Condition D1 | Condition E1 | Condition F1 |
| Condition A2 | Condition B2 | Condition C2 | Condition D2 | Condition E2 | Condition F2 |
| Condition A3 | Condition B3 | Condition C3 | | Condition E3 | Condition F3 |
| Condition A4 | Condition B4 | Condition C4 | | Condition E4 | Condition F4 |
| Condition A5 | | Condition C5 | | Condition E5 | |
| | | | | Condition E6 | |

**Figure 1**: A 6-parameter morphological field. The darkened cells define one of 4,800 possible (formal) configurations.

Obviously, in fields containing more than a handful of variables, it would be time-consuming – if not practically impossible – to examine all of the configurations involved. For instance, a 7-parameter field with 6 conditions under each parameter contains almost 280,000 possible configurations.

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 configurations which contain mutually contradictory conditions. In this way, we create a preliminary outcome or solution space within the morphological field without having first to consider all of the configurations as such.

This “reduction” is achieved by a process of *cross-consistency assessment* (CCA). 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 direction or causality, but only to mutual consistency. Using this technique, a typical morphological field can be reduced by to 90% or even 99%, depending on the problem structure.

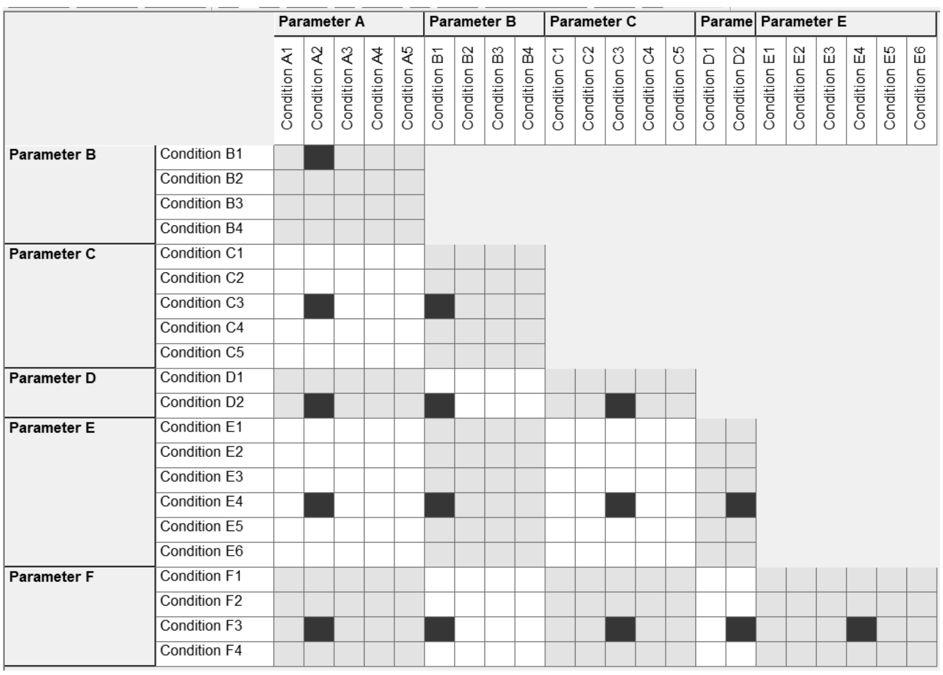



**Figure 2:** The cross-consistency matrix for the morphological field in Figure 1. The dark cells represent the 15 pair-wise relationships in the configuration given in Figure 1.

There are three principal types of inconsistencies involved in the cross-consistency assessment: purely *logical* contradictions (i.e. “contradictions in terms”); *empirical* constraints (i.e. relationships judged to be highly improbable or implausible on practical, empirical grounds), and *normative* constraints (although these must be used with great care, and clearly designated as such).

This technique of using pair-wise consistency assessments, in order to weed out internally inconsistent configurations, is made possible by the combinatorial relationships inherent in morphological models, or in any discrete configuration space. While the number of configurations in such a space grows factorially with each new parameter, the number of *pair-wise relationships between parameter conditions* grows only in proportion to the triangular number series – a quadratic polynomial. Naturally, there are also practical limits reached with quadratic growth. The point is, that a morphological field involving as many as 100,000 formal configurations can require no more than few hundred pair-wise assessments in order to create a solution space.

When this solution (or outcome) space is synthesized, the resultant morphological field function as an *inference model*, in which any parameter (or multiple parameters) can be selected as "input", and any others as "output". Thus, with dedicated computer support, the field can be turned into a laboratory with which one can designate different 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 immediately evident when they are cross-referenced and assessed for internal consistency. Like most methods dealing with complex social and organizational systems, GMA requires strong, experienced facilitation, an engaged group of subject specialists and a good deal of patience.

## 3. Four morphological models about OR/MS modelling

The four models presented here deal with decision support modelling from somewhat different perspectives. The generic focus question posited for the development of first three models was:

> What are the most important parameters concerning *which types of OR/MS modelling methods are most appropriate for different types of modelling tasks and modelling contexts*?

The four models differ in perspective in the following manner:

**M1** concerns modelling issues form an *academic or theoretical perspective*
**M2** concerns modelling issues more from an (OR) *practitioner perspective*
**M3** concerns multi-methodology modelling focusing on *stakeholder positions*
**M4** concerns a number of *basic properties* of modelling methods in general

First, some general considerations. When initially examining these models, there are three main points of interest:

1. Firstly, *how is the model dimensioned*, i.e. what set of factors (parameters) have been chosen in order to define and specify the model's *problem space*? This point is fairly self-evident and needs little comment. "Dimensioning" and "parameterizing" the problem space to be investigated is the basic first step in the analysis phase of any modelling process. It tells us what the model is about.

2. Secondly, how are the parameters *ordered in relation to each another (from left to right)*? This needs some explanation. In morphological modelling, the *order* in which the parameters appear in the morphological field has no affect on the model's performance. GMA is based on internally consistent *combinations* of factors, not *permutations*. Any particular parameter – or any set of parameters – can be designated as inputs (or as "independent variables"), and any as outputs, no matter where they appear in the field.

   However, when morphological models are clearly meant to display *inference* (as these models do) then the modellers tend – and are encouraged – to order their parameters from left to right in the form of an "if-then" sequence. In this way, they place what they consider to be the more important *influencing factors* (or "input parameters") on the left-hand side of the model, and the influenced (or "outcome parameters") on the right-hand side. Again, this ordering is not necessary, as any parameter(s), anywhere in the field, can be designated as input variable(s). However, this left-to-right ordering feels natural and tells us something about how the modellers are thinking in terms of what the model is supposed to *perform*: i.e. "*what questions are we asking of the model,* *and what types of answers do we want to get out of it*?" (I would *expect* – although have no experience in this – that this direction would tend to be reversed for morphologies done in languages that are written from right to left, e.g. Arabic or Farsi.)

3. Thirdly, *what is the nature of the model's solution space*? I.e. how does it behave as an input-output device? What types of "answers" (outputs) does it give for specific "questions" (inputs) asked? This depends on how the value ranges of the respective parameters are related to each other. As discussed in Section 2, these relationships are mapped out by a Cross-Consistency Assessment (CCA), which deletes all (logically) impossible and (empirically) implausible relationships, and leaves the model with an internally consistency solution or outcome space. It is the process of reducing a large *problem space* to a smaller, more manageable *solution space*, which is the basic point of GMA.

   This said, we are not primarily concerned with exploring the models' solution spaces here. Computer-aided morphological models are user-interactive: different types of inputs can be selected and different output configurations obtained. This interactive feature cannot be adequately represented "on paper". Only specific *examples* of input-output configurations can be displayed. (In these examples I have mainly focused on *non-quantified modelling problems*.) Only model **M4** (the meta-model of formal OR/MS modelling methods) has an outcome space small enough to be listed in its entirety.

A final note: On the computer, different types of input and output values are colour coded. This is used on order to identify different types of relationships and to facilitate comparisons between two or more configurations. In the following models, only three colour codes are used, which suffice in order to understand the models presented here.

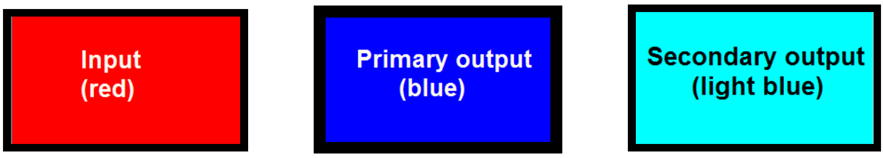



**Figure 3**. Colour code used to represent input and output values in the models presented.

By *Primary output* we mean an optimal, "normal" or expected output value associated with a particular (given) input. *Secondary output* is seen as *possible*, but judged as less likely, less relevant, or as a "wild card".

## M1: Model of decision support modelling from an "academic" perspective

The first two models (**M1** and **M2**) were developed at the Swedish Defence Research Agency (FOI – Stockholm) in 2000. We will refer to them as the "FOI models". They were developed in two separate lunch-to-lunch workshops, with two separate groups of subject specialists. The workshops were facilitated by the author and fellow morphologist Maria Stenström.

Given the limited time available, these small models are only to be considered prototypes. However, the general *form* of the models – and the obvious differences between them – is interesting in itself, reflecting the different positions and interests of the modellers involved.

**M1** was developed primarily by "academics" and theorists. The workshop participants were recruited from senior OR teaching staff at the Royal Institute of Technology (Stockholm), from the departments of applied mathematics at the Universities of Stockholm and Uppsala, and from the department of Theoretical Philosophy at the University of Lund. Also participating were two modelling theoreticians from the Swedish Defence Research Agency (FOI).

Because of the time constraints, the participants were asked to identify and define a maximum of 7 parameters. The following were finally agreed upon, in this order:

1. What, in general terms, is being modelled?
2. What is the *purpose or goal* of the modelling?
3. What is the desired *final result*?
4. What specific *methods of approach* can be applied?
5. From where is *knowledge derived*?
6. What type of *uncertainty transformation* is possible and/or required?
7. What general *modelling types* are applicable for the task?

Figure 4 shows the morphological field that was created on the basis of these parameters. First of all, we can see that the modellers were clearly interested in the *social context* of the modelling process, its purpose and results. This is seen in the first three parameters, the remaining four (on the right-hand side) telling us something about how we are to proceed and, expressly, which general modelling methods are most appropriate for the task at hand.

The example input-output configuration shown in the model concerns a policy driven problem of developing/adapting a social system (e.g. an institution, organisation, or legal system, etc.) to a changing (social/political) environment. The particular aim of the modelling process – at this stage at least – is to examine and recommend a policy position. The modelling methods recommended are all non-quantified, and the best that can be done with the uncertainties involved is to try to identify and specify them.

Of course, one may not agree with the choice of parameters, with their defined value ranges, or with the particular configuration shown. However, the point here is not to dictate what is "right" or "wrong", but to explore and bring relevant modelling issues to the fore, and to keep the process as transparent as possible.

| What is being modelled | Purpose or goal of modelling | Desired final result | Method of approach | From where is knowledge derived | Uncertainty transformation | Modelling type |
|---|---|---|---|---|---|---|
| Existing technical system | Adapt to new technology | Specific proposal for solution | Calculate/optimise | Statistical collation and compilation of available data | Specify uncertainly factors | System Dynamics Modelling/ Control engineering |
| Existing social system | Adapt to new social/political environment | To better structure and define the problem | Simulate | Assertions by stakeholders and problem owners | Reduce option space | Linear programming models |
| Design of technical system | Adapt to new economic/financial framework | Increase knowledge and competence within problem area | Compare/assess | Assertions by external, impartial groups | Better estimate of probability of outcome | Stochastic models (e.g. Monte Carlo) |
| Design of social system | Adapt to new sector tasks | To establish and legitimate an idea or a policy direction | Describe, shape, give conceptual form | (Our) own observations, depictions and interpretations | No transformation | Influence diagrams |
| | Adapt to other political goals | | | | | Morphological modelling |
| | To assess already existing system | | | | | Scenario narratives |
| | | | | | | "Rich pictures" |

**Figure 4:** The "academic" model of OR/MS modelling issues, with the first three parameters providing input conditions (grey), and the remaining parameters giving primary and secondary output. The 7 parameter model generates 43,008 formal configurations.

## M2: Model of decision support modelling from a "practitioner" perspective

Model **M2** was developed by a group of senior OR practitioners employed at the Swedish National Defence Research Agency, whose job was to provide decision support in such diverse areas as defence organisation and logistics, civil preparedness, international security and crisis management. Again, the model was restricted to 7 parameters. Here we see a somewhat different set of conditions as compared with model **M1;** i.e. they are more technical and introspective, and more focused on the different *phases* of the analysis and decision support process.

| Study Phase | Main type(s) of information available | Types of Method | Type(s) of competence required | MODE of work | Validation | Extent of "back-office" work |
|---|---|---|---|---|---|---|
| Problem formulation/ conceptualisation/ structuring | Numerical | Deterministic | Mathematical / math-statistical | Individual analyst | Mathematical/Logical | Much |
| Generation of alternatives (IF-THEN) | Logical | Stochastic | Philosophical / Epistemological | Small group of analysts | Experiment/ experience | Moderate |
| Analysis of possible solutions | Graphic | Iconological | Sociological/ Organisational/ Anthropological | Small group of analysts plus clients | Expert judgement | Very little or none |
| Interpretation, evaluation of result | Text/natural language | Structural (e.g. Influence diagrams) | Economics | Large group of analysts plus clients | Explicitly none | |
| Presentation/ recommendations | | Morphological Typological | Behavioural | Client/analyst network | | |
| | | Narrative | Historical Political science | | | |

**Figure 5:** Model 3.2 – the "practitioner" model of OR/MS modelling issues, showing inputs under "Study Phase" and "Main type of information available" (gray) and a clustered output of primary and secondary outputs. The 7 parameter model generates 46,200 formal configurations.

The main prerequisites (inputs) are the phase of the study (in the example shown, the *problem formulation* and *problem structuring* phase), and the nature of the task *as expressed* in the types of (empirical) information available. Again, the types of methods deemed applicable, and the competencies required, point to "soft" OR and non-quantified modelling, at least in this phase of the study. We note also that this model is more focused on how to work in groups and with the client, and *how to legitimise results* ("validation").

## M3: Multi-methodology model with stakeholder emphasis

Model **M3** was produced *at-a-distance* (via e-mail) as part of the Student Research Support Program provided by the Swedish Morphological Society [16]. It was developed by Ms. Mahnaz Hosseinzadeh at the Department of Management at the University of Tehran, as part of her PhD thesis [17].

In Dr. Hosseinzadeh's words:

> "In the first step of my PhD dissertation, I have investigated the philosophical foundations of OR/MSs methods and in the second step have tried to design a framework to assist in the process of multimethodology. For this purpose, eleven dimensions were indentified which, according to the experience of national experts, concern certain problematic situations while working on domestic organizational problems. … My aim of using Morphological Analysis is to be able to choose suitable methods when faced with a combination of conditions in a problematic situation. For example … given a situation with such and such characteristics (as a multi-driver input), what methodologies best fit this situation?" [Personal communication]

Since Dr. Hosseinzadeh was able to spend a good deal more time in developing the material, it is relatively more complete and, furthermore, provides an interesting contrast to the proceeding models.

The 12 parameter model shown in Figure 6 generates almost 2.7 million formal configurations. (NOTE: we only display the morphological field here, not any particular solutions or configurations.)

There are a number of interesting features in this model. Firstly, it treats a longer, more detailed list of "methods/methodologies", which are a mixture of "hard" (mathematical) and "soft" modelling methods, organisational planning processes and group interaction/facilitation methods – some of them developed by specific practitioners, e.g. Critical Heuristics [18], Soft Systems Methodology [19] and Strategic Choice [20].

Secondly, it explicitly identifies stakeholders and stakeholder relationships which are not present in the two FOI models. These are: 1) Stakeholder objectives; 2) Stakeholders' teamwork culture; 3) Level of Stakeholder trust in the scientific methodologies; and 4) Maturity of the methods in Iran (which I also consider to be a stakeholder issue).

This might be explained by the fact that the modeller had time to develop a considerably larger model, and that such stakeholder parameters might have been included in the two FOI models, had more time been given to their development. However, when I asked Dr. Hosseinzadeh to reduce her model to what she considered the 7 *most important* parameters, three of the four stakeholder parameters remained in the reduced field (Figure 7).

| Stakeholder objectives | Phase of Intervention | The level of access to objective variables and data | Stakeholders' teamwork culture | The maturity of method (ology) in Iran | The time necessary for gaining results by the use of the method (ology) | The nature of relationship between variables | The number of variables and their accessibility in the problem situation | The level of experience necessary for OR experts to employ the method (ology) | The level of Stakeholders' trust in the scientific methodologies for solving organizational problems | The time horizon of the method's result | Method (ology) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Unitary | Appreciation | Reliable data exist and are generally available to the OR experts | Tend to teamwork | Very high | Low | Absolute and certain | Limited in number (< 20) and mostly accessible | Low | Do not believe in scientific methodologies | Short-term | LP Linear Programming |
| Different objectives, the same level of | Analysis | Reliable data exist but are not generally available (Epistemic uncertainty) | Compete to gain personal interests | High | Middle | Probabilistic | Limited in number (< 20) and mostly inaccessible | Average | Believe only in the efficiency of mathematical modelling methods | Long-term | NLP Non- Linear Programming |
| Different objectives, different levels of | Assessment | Reliable data does not exist (Genuine uncertainty) | | Average | High | Ambiguous and genuinely uncertain | Large number (> 20) and mostly accessible | High | Believe in the efficiency of both quantitative and qualitative modelling | | SDM System Dynamics Modelling |
| | Action | | | Low | | | Large number (> 20) and mostly inaccessible | | | | VSM Viable System Models |
| | | | | Very low | | | | | | | SSM Soft Systems Methodology |
| | | | | | | | | | | | SODA Strategic Options Development Analysis |
| | | | | | | | | | | | IP Interactive Planning |
| | | | | | | | | | | | SAST Strategic Assumption Surfacing and Testing |
| | | | | | | | | | | | TS Team Syntegrity |
| | | | | | | | | | | | CSH Critical Systems Heuristics |
| | | | | | | | | | | | SC Strategic Choice |
| | | | | | | | | | | | GMA General Morphological Analysis |

**Figure 6**. Multi-methodology model with three stakeholder parameters.

| Stakeholder objectives | Phase of Intervention | Level of access to objective variables and data | Stakeholders' teamwork culture | Nature of the relationship between variables | Modelling method | The maturity of method in Iran |
|---|---|---|---|---|---|---|

**Figure 7**: The seven parameters of the reduced model

One might be tempted to explain this stakeholder focus by way of cultural differences: e.g. that stakeholder issues might be more important in certain countries and cultures than in others. I certainly do not discount this possibility: Besides Europe and the U.S., I have carried out GMA workshops in China, Japan, South Africa and Singapore, and can attest to differences in, for instance, openness, tolerance of dissention, demands for consensus, etc. However, in my experience, stakeholder issues of the types taken up by Dr. Hosseinzadeh have turned up *continually* in the work I have done during the past 30 years in all country settings, including Europe and the U.S. The difference is not in the existence of the problems, but in how we deal with them, and to what extent we even acknowledge them.

## M4: A morphology of modelling methods

This meta-model was produced *in house* at the Swedish Morphological Society (Stockholm) in connection with the article "Outline for a Morphology of Modelling Methods: Contribution to a General Theory of Modelling" [5]. It began as a totally introspective study: it employs a number of basic modelling properties in order to explore different possible, formal modelling "types". For this purpose, two criteria were put forward, which were considered to be *necessary* for something to be called a "scientific model" (at least as this is usually employed in OR/MS). The two criteria are:

- A scientific model must contain two or more mental constructs that can serve as *variables*, i.e. *dimensions* which (at least potentially) can support a range of values or states (e.g. variables such as age, gender, product type, or disposable income).

- One must be able to establish *relationships* either between the variable entities *as such*, or between the values of the *value ranges* within the variables (e.g. causal, probabilistic, logical, normative, etc.)

Out of these two basic criteria, it is possible to abstract a number of operational properties (or parameters) which more closely specify how models do their work, and by which different modelling methods can be identified, classified, exemplified and compared. The following five properties (which are not exhaustive) were treated:

***P1. Specification***: Are the variables of the model (*internally) specified* or only treated a black boxes?

***P2. Directionality:*** Are the connections between the variables *directed* or *non-directed (symmetrical)*?

***P3. Quantification***: Are the relationships of connectivity between the variables *quantified* or *non-quantified*?

***P4. Cyclicality:*** Does the model allow for *cyclic connectivity* between the variables, or is the model *acyclic*.

***P5. Type of connectivity***: What is the nature of the connective relationships between variables (e.g. causal, probabilistic, logical, normative etc.)?

These five parameters were chosen because they represent some of the simplest modelling properties that we can identify (for instance, P2, P3 and P4 are basic parameters in mathematical graph theory). They define the morphological field in Figure 8. This field contains 64 (2 x 2 x 2 x 2 x 4) possible "cases" or formal *configurations*, the one shown representing a *Bayesian Network Model*. The five properties do not necessarily represent *orthogonal relationships,* as some of them can be partially overlapping or contain properties that are logically contradictory. A *cross-consistency assessment* (CCA) of these properties will allow us to identify and weed out such contradictions, thus removing from the problem space any configurations which contain incompatible properties.

Figure 9 shows the Cross-Consistency Assessment of the model in Figure 8. The assessment was "liberal", in the sense that it allows everything that is not blatantly contradictory. It reduces the problem space of 64 configurations to a solution space of 42 possible modelling types (more that I originally thought would be the case).

| **Specification (of variables)** | **Directionality (of relationships between variables)** | **Quantification (of relationships between variables)** | **Cyclic relationships (between variables)** | **Type of connectivity (of the relationships between variables):** |
|---|---|---|---|---|
| Specified value range | Directed | Quantified | Cyclic | Causal: mathematical-functional |
| Non-specified value range ("Black boxes") | Not directed | Non-quantified | Acyclic | Causal: probabilistic |
| | | | | Quasi-causal (influence) |
| | | | | Non-causal (E.g. logical/normative) |

**Figure 8**: Morphological field consisting of five modelling properties and 64 possible configurations – one shown, representing "Bayesian Network Models".

| | | Intern | | Conne | | Model | | Cyclic | |
|---|---|---|---|---|---|---|---|---|---|
| | | Variables internally specified | Variables non-specified | Directed | Not directed | Model is quantified | Model is non-quantified | Cyclic | Acyclic |
| **Connections between the variables:** | Directed | - | - | | | | | | |
| | Not directed | - | - | | | | | | |
| **Model quantification** | Model is quantified | - | - | - | - | | | | |
| | Model is non-quantified | - | - | - | - | | | | |
| **Cyclic feedback/ recursion** | Cyclic | - | - | - | - | - | - | | |
| | Acyclic | - | - | - | - | - | - | | |
| **Mode of connectedness between variables** | Causal: math-funct. | - | X | - | X | - | X | - | - |
| | Causal: probabilistic | - | - | - | - | - | X | - | - |
| | Quasi-causal (influence) | - | - | - | - | - | - | - | - |
| | Non-causal | - | - | - | - | - | - | - | - |

**Figure 9**: The Cross-Consistency matrix for field in Figure 7, showing four formal constraints marked with "X".

All of the (more or less) well-know and established modelling types are easily identifiable in this model – from *Systems Dynamics Models*, *Bayesian models*; different forms of *influence diagrams* (weighted; non-weighted; directed; symmetrical, etc.); *analytic hierarchies*; *decision trees* and, of course, *morphological models* themselves. Figure 10 shows the complete list of possible modelling types contained in the meta-model. (One might suspect that some of these possible theoretical modelling types would be of marginal utility or just plain weird. However, as we all know, "weird" things can sometimes lead to interesting discoveries.)

| # | Propertyes (modelling Parameter) --> Modelling types | ***Internal specification*** of variables | ***Directionality*** of relationships | ***Quantification*** of relationships | ***Cyclic?*** | ***Type*** of connectivity |
|---|---|---|---|---|---|---|
| 1 | Morphological models (GMA) | **yes** | **no** | **no** | **yes** | **Non-causal** |
| 2 | System Dynamic Modelling (SDM) | **yes** | **yes** | **yes** | **yes** | **Mathematical** |
| 3 | Bayesian Network modelling (BNM) | **yes** | **yes** | **yes** | **no** | **Probabilistic** |
| 4 | Weighted influence diagrams | **no** | **yes** | **yes** | **yes** | **Quasi-causal** |
| 5 | Non-quantified influence diagrams | **no** | **yes** | **no** | **yes** | **Quasi-causal** |
| 6 | Un-directed, non-quantified graph | **no** | **no** | **no** | **yes** | **Non-causal** |
| 7 | Probabilistic Tree Diagram | **no** | **yes** | **yes** | **no** | **Probabilistic** |
| 8 | Un-Weighted Analytical Hierarchy | **no** | **yes** | **no** | **no** | **Non-causal** |
| 9 | | yes | yes | yes | no | Mathematical |
| 10 | | no | yes | yes | no | Quasi-causal |
| 11 | | yes | yes | yes | yes | Quasi-causal |
| 12 | | yes | yes | no | yes | Quasi-causal |
| 13 | | no | no | no | yes | Quasi-causal |
| 14 | | yes | yes | yes | no | Quasi-causal |
| 15 | | no | yes | no | no | Quasi-causal |
| 16 | | yes | yes | no | yes | Quasi-causal |
| 17 | | no | yes | no | yes | Quasi-causal |
| 18 | | no | no | yes | yes | Quasi-causal |
| 19 | | yes | no | no | yes | Quasi-causal |
| 20 | | yes | yes | no | no | Quasi-causal |
| 21 | | yes | no | yes | yes | Quasi-causal |
| 22 | | no | no | yes | no | Quasi-causal |
| 23 | | no | no | no | no | Quasi-causal |
| 24 | | yes | no | no | no | Quasi-causal |
| 25 | | yes | no | yes | no | Quasi-causal |
| 26 | | yes | yes | yes | yes | Non-causal |
| 27 | | no | yes | yes | yes | Non-causal |
| 28 | | yes | no | yes | yes | Non-causal |
| 29 | | no | no | yes | yes | Non-causal |
| 30 | | yes | yes | yes | no | Non-causal |
| 31 | | no | yes | yes | no | Non-causal |
| 32 | | yes | yes | no | no | Non-causal |
| 33 | | yes | no | no | no | Non-causal |
| 34 | | no | no | no | no | Non-causal |
| 35 | | yes | no | yes | no | Non-causal |
| 36 | | no | no | yes | no | Non-causal |
| 37 | | yes | yes | yes | yes | Probabilistic |
| 38 | | no | yes | yes | yes | Probabilistic |
| 39 | | no | no | yes | yes | Probabilistic |
| 40 | | yes | no | yes | no | Probabilistic |
| 41 | | no | no | yes | no | Probabilistic |
| 42 | | yes | no | yes | yes | Probabilistic |

Figure 10. 42 modelling types classified by way of 5 properties. Modelling types 9-42 are sorted by "type of connectivity".

## 4. Assessing the meta-modelling task with the meta-models

The natural next step, or course, is to use the two FOI meta-models (**M1** & **M2**) to "measure" themselves – i.e. to assess the nature of the very meta-modelling task involved in producing them. This is not merely an act of self-indulgence, but an appropriate act of self-examination and self-critique.

Let us begin with M1, the "academic" model of OR/MS modelling. In this case, we are not concerned with "inference", but simply seek to situate the meta-modelling task within the framework of the meta-model itself. The closest that I am able to represent this task is shown in Figure 11 (dark blue cells = primary specifications; light blue cells = secondary *possible* specifications).

What I think is most interesting in this context are the questions that arise from the first two parameters. In the parameter "What is being modelled?" one must ask if the two possibilities of "technical" and "social" systems are adequate. In fact, we are modelling a *conceptual system* (i.e. "scientific modelling methods"), although within a social context. But this is only implied in the meta-model. In retrospect, it might have been appropriate to have included the categories of modelling "Existing conceptual systems" and "Designing new conceptual systems".

This leads to the next question and the next parameter: "Purpose or goal of modelling". While the meta-modelling task was certainly to "assess an already existing (conceptual) system", it might also be associated with the design of new conceptual systems and the development of new "sector tasks", i.e. those concerned with the continued expansion of OR/MS modelling into new types of e.g. policy driven processes.

| What is being modelled | Purpose or goal of modelling | Desired final result | Method of approach | From where is knowledge derived | Uncertainty transformation | Modelling type |
|---|---|---|---|---|---|---|
| Existing technical system | Adapt to new technology | Specific proposal for solution | Calculate/optimise | Statistical collation and compilation of available data | Specify uncertainly factors | System Dynamics Modelling/ Control engineering |
| Existing social system | Adapt to new social/political environment | To better structure and define the problem | Simulate | Assertions by stakeholders and problem owners | Reduce option space | Linear programming models |
| Design of technical system | Adapt to new economic/financial framework | Increase knowledge and competence within problem area | Compare/assess | Assertions by external, impartial groups | Better estimate of probability of outcome | Stochastic models (e.g. Monte Carlo) |
| Design of social system | Adapt to new sector tasks | To establish and legitimate an idea or a policy direction | Describe, shape, give conceptual form | (Our) own observations, depictions and interpretations | No transformation | Influence diagrams |
| | Adapt to other political goals | | | | | Morphological modelling |
| | To assess already existing system | | | | | Scenario narratives |
| | | | | | | "Rich pictures" |

Figure 11. The "academic" model of OR/MS modelling as applied to the task of its own development.

Figure 12 shows the assessment of the meta-modelling task in the framework of the "practitioner" model (**M2**). Here I think that the assessment works somewhat more smoothly. The "Study Phase" is clearly "Problem formulation/conceptualisation", and (when working with inference) "Generating alternatives". But it also has a potential for all of the other alternatives. The "Types of competence required" tend more towards the epistemological and the "sociology of science", rather than the mathematical and technical. Finally, although the only "validation" method we had at the time was that of "expert judgement", one might very well apply case studies and even practical experiments to judge the validity of the posited relationships in the model.

| Study Phase | Main type(s) of information available | Types of Method | Type(s) of competence required | MODE of work | Validation | Extent of "back-office" work |
|---|---|---|---|---|---|---|
| Problem formulation/ conceptualisation/ structuring | Numerical | Deterministic | Mathematical / math-statistical | Individual analyst | Mathematical/Logical | Much |
| Generation of alternatives (IF-THEN) | Logical | Stochastic | Philosophical / Epistemological | Small group of analysts | Experiment/ experience | Moderate |
| Analysis of possible solutions | Graphic | Iconological | Sociological/ Organisational/ Anthropological | Small group of analysts plus clients | Expert judgement | Very little or none |
| Interpretation, evaluation of result | Text/natural language | Structural (e.g. Influence diagrams) | Economics | Large group of analysts plus clients | Explicitly none | |
| Presentation/ recommendations | | Morphological Typological | Behavioural | Client/analyst network | | |
| | | Narrative | Historical Political science | | | |

Figure 12. The “practitioner” model of OR/MS modelling as applied to the task of its own development.

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