Modelling Society's Capacity to Manage Extraordinary Events

Developing a Generic Design Basis (GDB) Model for Extraordinary Societal Events using Computer-Aided Morphological Analysis

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Tom Ritchey, Anna-Lena Lövkvist-Andersen, Richard Olsson, Maria Stenström

(Contact: ritchey@swemorph.com)

Abstract
Extraordinary societal events are – by definition – rare events which cannot be adequately treated on the basis of measurable probabilities and traditional risk analysis. The complex socio-technical and ideological processes involved are difficult to predict or causally simulate. Instead, such "risks" must be studied and treated from the perspective of *genuine uncertainty*. The Swedish Emergency Management Agency (SEMA) and the Swedish Defence Research Agency (FOI) are developing a Generic Design Basis (GDB) model as *strategic decision support* for treating the uncertainties involved in the emergence of extreme societal events. The model is being developed with the aid of computerized *morphological analysis*. The staring point is the identification, structuring and analysis of undesirable *consequences* for society (i.e. effects), rather than any fix set of causes. These consequences are defined *inter alia* on the basis of *political values and norms*, which take the form of a national security strategy. The aim is to identify and set priorities between different measures which will increase Sweden's capacity to manage extreme events which represent serious threats to society.

Introduction

In his seminal work "Risk, Uncertainty, and Profit", Frank Knight (1921) established the distinction between *risk* and *uncertainty*.

> "… Uncertainty must be taken in a sense radically distinct from the familiar notion of Risk, from which it has never been properly separated. … The essential fact is that "risk" means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomena depending on which of the two is really present and operating. … It will appear that a *measurable* uncertainty, or "risk" proper, as we shall use the term, is so far different from an *un-measurable* one that it is not in effect an uncertainty at all."

Risk is defined as uncertainty based on a well grounded (quantitative) probability. Formally, Risk = (the probability that some event will occur) X (the consequences if it does occur). *Genuine uncertainty*, on the other hand, cannot be assigned such a (well grounded) probability. Furthermore, genuine uncertainty can often not be reduced significantly by attempting to gain more information about the phenomena in question and their causes.

Today, in working with relatively high level social, political, organisational and ideological systems, what we often call *risk analysis* is properly a matter concerning *genuine uncertainty*.

This is especially the case with what is generally referred to as "extraordinary societal events".
The Swedish Emergency Management Agency (SEMA) and the Swedish Defence Research Agency (FOI) are developing a *strategic decision support model* for treating the uncertainties involved in the emergence of extraordinary societal events. The aim is to identify and set priorities between different measures which will increase our capacity to manage such events, which represent serious threats to society. For this purpose, a Generic Design Basis (GDB) model is being developed using the non-quantified modelling method *morphological analysis*.

The purpose of the GDB-study is:

- to create a common set of internally related parameters for identifying extraordinary societal events and,
- to develop methods to make priorities between different measures aimed at strengthening society's collective capacity to manage such events.

The main aim of the GDB model is to link the operational level of Sweden's ongoing program for Risk and Vulnerability Analysis (RVA) to an overall national security strategy.

This paper will continue with a discussion of some of the methodological problems confronting the study of extraordinary societal events. This will be followed by a presentation of the fundamentals of morphological analysis as a general method for non-quantified modelling. Finally, we will describe how computer aided morphological analysis is being applied to develop *strategic decision support models* for treating the uncertainties involved in extraordinary societal events.

Methodological background: Non-quantified modelling

Modelling complex socio-technical and organizational systems presents us with a number of difficult methodological problems. Firstly, many of the factors involved are not meaningfully quantifiable, since they contain strong political and ideological dimensions. This means that traditional quantitative methods, mathematical 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 includes both antagonistic uncertainty (conscious, wilful actions among actors) and so-called non-specified uncertainty (for instance, uncertainties concerning what types of scientific and technological discoveries will be made in the future). This represents even a greater blow to mathematical modelling, and especially to traditional (quantitative) risk analysis.

Finally, the creative 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 iterative process from problem formulation, through alternative generation 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 mathematical modelling and (quantitative) risk analysis is a form of non-quantified modelling relying on judgmental processes, logical relationships and internal consistency, rather than on causal relationships and probabilities. Traditional risk analysis, when applicable, can – and should – be used as an aid to judgment. However, at a certain level of complexity (e.g. at the social, political and cognitive level), judgment 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 systems and policy fields can be analyzed into any number of non-quantified variables and ranges of conditions. Similarly, sets of non-quantified conditions can be synthesized 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

General Morphological Analysis (MA) is a non-quantified modelling method for structuring and analyzing complex social, organizational and technical problem fields (Ritchey, 1998). It can be used for developing risk/threat scenarios, for analyzing complex policy spaces or for studying the relationship between means and ends in strategic planning.

MA was developed in the 1930's and 1940's by Caltech professor Fritz Zwicky as a general method for structuring and investigating the total set of relationships contained in multi-dimensional, usually non-quantifiable, problem complexes. From the late 1960s to the early 1990s, a limited form of MA was employed by a number of engineers, operational researchers and policy analysts for structuring complex engineering problems, developing scenarios and studying security policy options (Ayres, 1969; Bridgewater, 1969; Müller-Merbach, 1976; Rhyne, 1981). However, these earlier studies were carried out by hand or with only rudimentary computer support, which is highly time-consuming, prone to errors, and severely limits the range of parameters that can be treated.

In 1995, two of the authors (Ritchey and Stenström), working at the Institution for Technology Foresight and Assessment at Totalförsvarets Forskningsinstitut (FOI – the Swedish Defense Research Agency in Stockholm) realized that general morphological analysis would never reach its full potential without carefully designed, dedicated computer support. The system we began developing then – and which is presently in its forth development stage – fully supports both the analysis-synthesis cycles inherent in MA, and makes it possible to create morphological inference models (Ritchey, 2003). Such models allow us to hypothesize varying initial conditions, define drivers and generate solutions or decision paths.

In morphological analysis, a multi-dimensional configuration space – or "morphological field" – is developed which describes the parameters of the problem complex to be studied, as well as their internal connections. One of the major advantages of this structuring method is that, with computer support, this "field" can be turned into a non-quantified ("if-then") inference model, in which varying initial conditions can be hypothesized, and alternative outcomes or scenarios examined.

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

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

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

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

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

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

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

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

Figure 2: Cross-consistency matrix for the 5-parameter morphological field in Figure 1.

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

In developing the GDB-model for the Swedish Risk and Vulnerability Analysis program, we began with a hypothesis concerning a meta-model consisting of abstract "gestalts" in the form of empty but named morphological fields (see Figure 3, below). We then attempted to identify the parameters of the different fields and their associated values (analysis phase). Each field was then "validated" by introducing real or hypothesized events, capacities and environments as field configurations (synthesis phase). This led to the reformulation of the meta-model, and a new analysis-synthesis cycle was initiated.

The iterations between the development of the morphological fields and the meta-model were necessary in order to gain a better understanding of the basic character of the problem complex – which included not only structuring the GDB-model itself, but also consisted of creating a process by which the actors involved could develop shared concepts and a common working interface.

A Generic Design Basis (GDB) model for Swedish Risk and Vulnerability Studies

In order to gain an overview of society's capacity to manage extreme events, we need to be able to make trustworthy estimates of both current preparedness levels, and of how to prioritise between different measures for improvement. This is a classical example of cost-benefit analysis.

However, the information currently available, in the form of earlier risk and vulnerability analyses (RVAs) for different Swedish societal functions and their technical systems, does not suffice in order to make such (trustworthy) estimates. These analyses only describe risks and vulnerabilities for individual functions and systems. Furthermore, the analyses were made separately for different societal levels (local, regional, national) and are not based on a common set of scenarios or a generally agreed upon methodology.

We even lack the criteria and a common framework for evaluating the notion of "capacity". Whereas responsible government agencies often issue directives calling for "adequate capacity", they do not describe what this would imply under different circumstances. For this reason, there is no systematic knowledge-base for estimating the "lack of capacity" at the overall national level. This, in turn, means that we have no trustworthy basis for making priorities for future improvements.

The principle focus of the GDB model is to create an overall picture of society's capacity to manage extreme events. This consists both of the operative capacities of many societal actors and of their collective crisis management capabilities, as well as the capacity of the technical infrastructure to provide services under different circumstances.

Classical *risk analysis* is principally concerned with investigating the risks surrounding physical plant, its design and operations. Such analyses tend to focus on *causes* and the direct consequences for the studied object. *Vulnerability analysis*, on the other hand, focuses both on consequences for the object itself and on primary and secondary consequences for the surrounding environment. It also concerns itself with the possibilities of reducing such consequences and of improving the capacity to manage future incidents.

However, in the case of rare and extreme societal events, we are presented with two major obstructions to classical risk and vulnerability studies. We have very little prior evidential knowledge upon which to base prediction; and it is impossible to track all of the cause-effect chains involved in the propagation of such extreme events. What we *can* study, however, are the *potential consequences* of different hypothesised extreme events – consequences which we wish to reduce by directing resources towards the right mitigation measures.

Thus, the point of departure for the GDB study was the identification, structuring and analysis of *undesirable consequences* for society (i.e. effects), rather than any fix set of causes. These consequences are defined inter alia on the basis of *political values and norms*, which can take the form of a national security strategy. In this way, the GDB-model has the same perspective as a vulnerability analysis, but concerns itself with society in general, rather than with specific technical systems or operations. (Hypothetical causes – i.e. natural, technological or antagonistic – can be associated with given consequences afterwards, in order to estimate *policy based* likelihoods and to dimension *preventive* measures.)

For the same reasons as discussed above, it is exceedingly difficult to plan in any detail for emergent societal risks and rare, extreme events. In lieu of this, however, it is possible to create a generic preparedness interface, a common perspective and shared concepts among concerned actors. The GDB-model will support this effort by creating a generic form for expressing and compiling the results of RVAs from different actors, and for shaping these into a profile for the measure of national preparedness capacity.

The GDB model

The Generic Design Basis model consists of sets of structured parameters, which support the identification and selection of possible societal consequences (as effects), the identification of capacities required for managing such consequences, and the decisions which must be made in order to set crisis management priorities concerning these capacities. The model should also support the actual process of risk and vulnerability analyses to be carried out by different social actors (agencies and authorities).

The GDB-model consists of four morphological fields (figure 3).

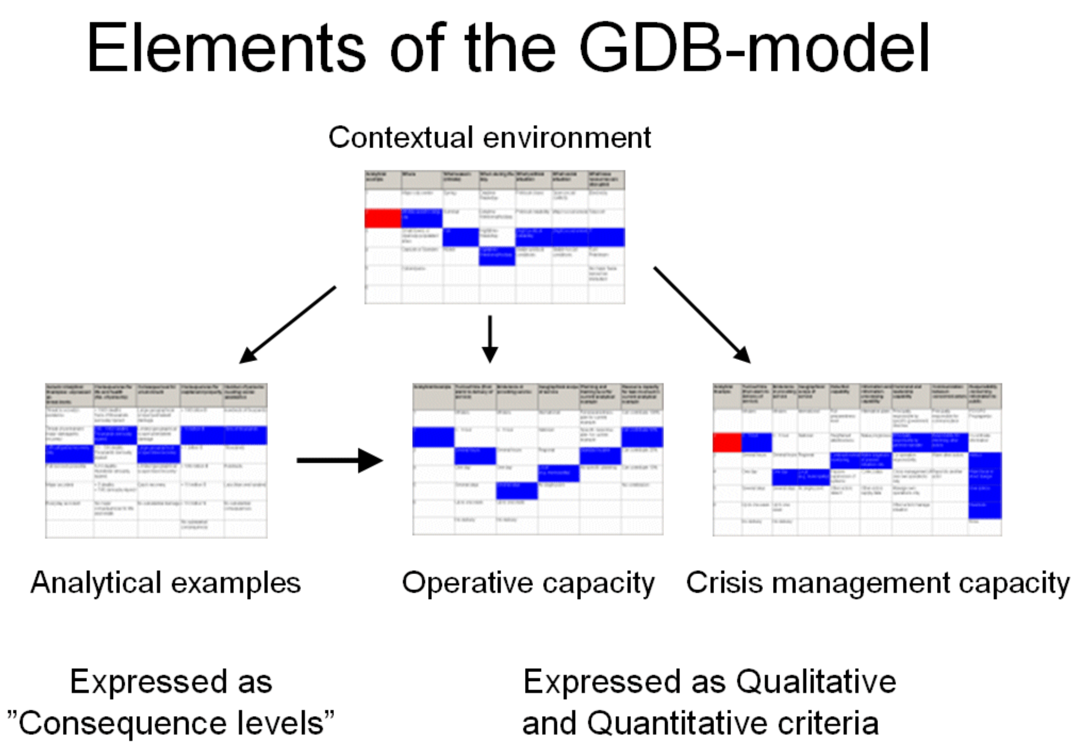

Figure 3. The GDG meta-model consisting of four morphological fields.

1. *Analytical examples*: These are a broad spectrum of societal consequences for life, health, social needs, the environment and the economy. They are modelled in a 5-dimensional morphological field. The model makes it possible to derive different hypothetical causes of such effects. The level of these consequences falls between everyday accidents and total societal collapse.

2. *Operative capacity*: These are expressed as qualitative and quantitative criteria for describing actors' *individual capacities* to carry out their own designated activities and operations, in order to manage situations expressed as consequences in the analytical examples.

3. *Crisis management capacity*: These are qualitative and quantitative criteria which describe the actors' *collective capacity* for crisis management.

4. *Contextual environments:* These describe different societal contexts for the consequences of extreme events. This includes such variables as weather, the political and social climate, and the capacity of the infrastructure to provide needed services.

Analytical examples

An analytical example is expressed in the form of a consequence profile along a number of parameters (Figure 4). Such a consequence profile can have several possible causes, which can be hypothesized (afterwards) in order to test the credibility of particular analytical examples. However, such causes are not necessary in order to dimension crisis management capacity for the consequences *per se*.

Generic Analytical Examples: expressed as threat levels	Where taking place	Number of fatalities	Number of seriously injured	Consequences for environment	Consequences for capital and property	Number of persons needing social assistance
Threat to society's existence	Far from Sweden	> 1 million deaths	Millions	Large geographical scope/ permanent damage	> 1000 billion $	Millions
Threat of permanent major damage	Close to Sweden	100, 000 - 1 million deaths	Hundreds of thousands	Limited geographical scope/ permanent damage	> 100 billion $	Hundreds of thousands
Major societal damage Only partial recovery	Partially in Sweden	> 10,000 - 100,000 deaths	Ten of thousands	Large geographical scope/ slow recovery	> 10 billion $	Tens of thousands
Major societal damage Full recovery possible	Only in Sweden	> 1000 - 10,000 deaths	Thousands	Limited geographical scope/ slow recovery	> 1 billion $	Thousands
Major accident		100 - 1000 deaths	Hundreds	Quick recovery	> 100 million $	Hundreds
Everyday accident		10 - 100 deaths Thousands injured	10 - 100	No substantial damage	< 10 million $	Less than one hundred
		< 10 deaths	< 10 seriously injured			

Figure 4. The morphological field "Analytical Examples", with which "consequence profiles" or scenarios can be generated. This particular field can generate tens of thousands of different profiles, although not all of these are credible. The highlighted consequence profile could, for instance, be the result of a damn bursting in northern Sweden.

The field can be utilised in several ways, for instance:

1. To define a number of consequence profiles to test the capacities of central, regional or local authorities, actors or systems. Other actors and required capacities can also be identified (see below)
2. To identify the consequences of scenarios that have already been developed by other actors, thus make it possible to have a standard benchmark.

3. To establish or (normatively) define the boundaries between extreme events, serious events and everyday events or accidents.
4. To define a series of events which can be combined into scenarios for education and training.

When a specific actor defines a specific consequence profile to work with, that actor's associated geo-demographic situation should also be included, so that the resulting scenario is as "reality-based" as possible.

Operative capacity

The morphological field "Operative capacity" (Figure 5) allows each actor to define a *capacity profile* for any analytical example. The profile can be mapped out sequentially, over time, and it is especially important to identify "tipping points" over given time periods. The field can also be used normatively, in order to define a sufficient or acceptable capacity for a given analytical example. By comparing actors' capacity profiles with normative profiles for different analytical examples, deficiencies can be identified.

Analytical Example	Turnout time (from alarm to delivery of service)	Endurance in providing service	Geographical scope of service	Planning and training level for current analytical example	Resource capacity for task involved in current analytical example
1	Minutes	Minutes	International	Full preparedness plan for current example	Can contribute 100%
2	C. 1 hour	C. 1 hour	National	Specific response plan for current example	Can contribute 50%
3	Several hours	Several hours	Regional	Standard routine	Can contribute 25%
4	One day	One day	Local (e.g. municipality)	No specific planning	Can contribute 10%
5	Several days	Several days	At single point		No contribution
6	Up to one week	Up to one week			
	No delivery	No delivery			

Figure 5: Operative capacity field.

Crisis management (CM) capacity

Emergent societal risks and extreme events must be managed by organisations with flexible, organic structures, since it is not possible to plan for such events in any detail. This means that actors must have compatible interfaces through which to interact, and that strategic management levels are knowledgeable about the CM capacities that these actors possess. To describe these interfaces and capacities, a morphological filed with eight parameters is employed (Figure 6). This field is used in the same way as that of "Operative capacity", i.e. both descriptive and normative.

Analytical Example	Turnout time (from alarm to delivery of service)	Endurance in providing service	Geographical scope of service	Detection capability	Information and information processing capability	Command and leadership capability	Communication between concerned actors	Responsibility concerning information to public
1	Minutes	Minutes	International	Full preparedness level	Alternative plans	Principally responsible by specific government directive	Principally responsible for communication	PSYOPS Propaganda
2	C. 1 hour	C. 1 hour	National	Heightened attentiveness	Make prognoses	Principally responsible by general mandate	Responsible for informing other actors	Co-ordinate information
3	Several hours	Several hours	Regional	Continual normal monitoring	Make diagnosis of present situation only	Co-operative responsibility	Warn other actors	Instruct
4	One day	One day	Local (e.g. municipality)	Passive supervision of systems	Collect data	Crisis management of one own operations only	Report to another actor	Warn those in direct danger
5	Several days	Several days	At single point	Other actors detect	Other actors supply data	Manage own operations only		Give advice
6	Up to one week	Up to one week				Other actors manage situation		Reassure
	No delivery	No delivery						None

Figure 6. Morphological field for actors' crisis management capacity.

Contextual environment

The morphological field "Contextual environment" (Figure 7) is used to qualify specific analytical examples, and to support judgements made about operative and CM capacity. It identifies social, political and geo-demographic constraints.

Analytical exemple	Where	What season (climate)	When during the day	What political situation	What social situation	What base resources are disrupted
1	Major city center	Spring	Daytime Weekday	Political chaos	Open social conflicts	Electricity
2	Middle-sized to large city	Summar	Daytime Weekend/holiday	Political instability	Major social unrest	Telecom
3	Small towns or sparsely-populated area	Fall	Nighttime Weekday	Slight political instability	Slight social unrest	IT
4	Outside of Sweden	Winter	Nighttime Weekend/holiday	Stable political conditions	Stable social conditions	Fuel Petroleum
5	Cyberspace					No major base resources disrputed
6						

Figure 7. The morphological field "Contextual environment".

Results and continued work

The GDB-model is a prototype which has been successfully tested at local and regional levels in Sweden. Future tests are being planned. The model will be developed as a flexible instrument which can be applied at municipal, regional and central government levels. It will also be adapted and made available to industry and trade sectors in order to create a common risk and crisis management framework, and to facilitate dialogue between different societal sectors.

The GDB-model is intended to support:

- the selection of analytical examples (scenario frameworks) for extraordinary events
- the identification of actors concerned with different analytical examples
- the development of a common, shared perspective concerning current capacities
- the comparison of overall capacities and defined norms
- the identification of possible measures for improvement
- making priorities between measures, including where they should be directed
- the identification of societal dependencies and the mapping of second and third order consequences

The Author: Dr. Tom Ritchey is a former Research Director for the *Institution for Technology Foresight and Assessment* at the Swedish National Defence Research Agency (FOI) in Stockholm. He is a methodologist and facilitator who works primarily with non-quantified decision support modelling -- especially with General Morphological Analysis (MA), Bayesian Networks (BN) and Multi-Criteria Decision support. Since 1995 he has directed more than 80 projects involving computer aided MA for Swedish government agencies, national and international NGO:s and private companies. He is the founder of the Swedish Morphological Society, Director of Ritchey Consulting and a founding partner of the U.K. base Strategy Foresight Partnership LLP.

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