Nuclear Facilities and Sabotage: Using Morphological Analysis as a Scenario and Strategy Development Laboratory

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Abstract

Modelling complex socio-technical systems and threat scenarios presents us with a number of difficult methodological problems. Most of the parameters involved are not meaningfully quantifiable, and we are faced with both antagonistic and non-specified uncertainties. Morphological analysis (MA), pioneered by Fritz Zwicky in the 1930s and 40s, is a method for investigating the totality of relationships contained in multi-dimensional, non-quantifiable problem complexes. During the past two decades, MA has been extended, computerised and applied in the area of futures studies and for structuring and analysing complex policy spaces. This article outlines the fundamentals of the morphological approach and describes recent applications in modelling threat scenarios and revised preparedness planning for nuclear facilities in Sweden.

Keywords - methodology; morphological analysis, Fritz Zwicky, non-quantified modelling, complex system modelling, threat scenarios, preparedness planning, nuclear facilities, sabotage.

INTRODUCTION

Morphological analysis (MA) was developed by Fritz Zwicky – the Swiss-American astrophysicist and aerospace scientist based at the California Institute of Technology (CalTech) – as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes (Zwicky 1966, 1969; Ritchey, 1998)). In this sense, MA is general method for non-quantified modelling using natural language categories and concepts.

During the past 20 years, MA has been extended and applied by a number of analysts and researchers in the U.S.A and Europe in the field of policy analysis and futures studies (Rhyne 1981, 1995a, 1995b; Coyle *et.al*. 1994, 1995; Ritchey 1997, 1998; Stenström & Ritchey 2001). The method is presently experiencing somewhat of a renaissance, not the least because of the development of small, fast computers and flexible graphic interfaces.

This paper will begin with a short discussion of some of the methodological problems confronting complex, non-quantified systems modelling 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 in modelling threat scenarios and revised preparedness planning for nuclear facilities in Sweden.

METHODOLOGICAL BACKGROUND

Modelling complex socio-technical systems and developing threat scenarios presents us with a number of difficult methodological problems. Firstly, most of the factors involved are non-quantifiable, since they contain strong social, political and ethical dimensions. Also, 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 self-reference 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).

Furthermore, the creative process by which these types of problem complexes are treated 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.

Morphological Analysis (MA) is a method for structuring and analyzing multi-dimensional technical, social and political problem complexes, which do not lend themselves to quantification. It can be used for developing scenarios, for defining and analyzing complex policy spaces and for assessing the relationship between ends and means in strategic planning.

MA was developed in order to facilitate group work and co-operation both between different scientific disciplines and between actors in different sectors and organizational levels in society. Importantly, the MA process encourages the investigation of extreme boundary values, and leaves a solid "audit trail" for future reference.

The end result of such an analysis is a morphological field which describes the total problem complex, and which can be used as an "if-then" laboratory in order to test various inputs against possible outputs.

Because of the complexity of the process, and the many thousands of potential configurations mapped out in even relatively small morphological fields, MA is difficult to employ without computer support. For this reason, FOA has developed MA/Casper (Computer Aided Scenario and Problem Evaluation Routine)[1], which supports the entire MA-process.

MA goes through cycles of analysis and synthesis in a number of iterative steps. The iterative steps are:

Analysis phase: Define the problem complex in terms of variables and variable conditions.

Step 1: Identify the dimensions, parameters or variables, which best define the essential nature of the problem complex or scenario. This is no trivial task and should be given ample time, depending on the nature of the problem. One should work with no more than 6-7 variables at a time.
Step 2: For each variable, define a range of relevant, discrete values or conditions, which the variable can express.

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[1] Casper is a proprietary software package developed and owned by the Swedish Defence Research Agency. For further information, contact Dr. Tom Ritchey at: ritchey@foi.se

The variable and variable-condition matrix is the morphological field -- an n-dimensional configuration space, which implicitly contains an outcome space for the problem complex thus defined. This outcome (or solution) space must then be defined.

Synthesis phase: Link variables and synthesize an outcome space.

Step 3: Assess the internal consistency of all pairs of variable conditions, identifying all inconsistent or contradictory pairs. This is an important step both for verifying the quality of the morphological field (vaguely defined concepts are immediately revealed in this process), and preparing for its reduction.

Step 4: Synthesize an internally consistent outcome space. MA/Casper does this by running through all of the possible formal outcomes (configurations) in the morphological field (there can be many thousands or millions) and "reducing" the field by throwing out all outcomes containing internal contradictions. This leaves a "solution space".

Step 5: Iterate the process if necessary. Scrutinize the solution space and return to steps 1, 2 and 3 in order to adjust variables, alternatives and consistency measures. Run steps 4 and 5 again.

At this point, one has created a non-quantified "if-then" (or input-output) laboratory within which one can define drivers, assume different conditions, and find ranges of associated solutions. In such a laboratory, anything can be designated as input (drivers or independent variables), and anything as output.

CREATING SCENARIO LABORATORIES AND MODELLING PREPAREDNESS PLANNING

The Swedish Defence Research Agency (FOI) has utilised morphological analysis and the MA/Casper system in some 40 projects during the past 10 years.

MA-projects typically involve developing computerised laboratories for generating scenarios and modelling complex systems involving a wide range of disparate, non-quantified variables. Such laboratories have been developed as instruments for *inter alia*: generating threat scenarios for Swedish national defence; identifying alternative long-term social evolutionary trends for the Swedish Nuclear Waste Management agency; and developing and evaluating alternative Extended Producer Responsibility (EPR) policies, in which different strategies can be pitted against a range of possible futures scenarios.

In 2002, FOI was contracted by the Swedish Nuclear Power Inspectorate (SKI) to help develop conceptual laboratories for evaluating a new range of threat scenarios and alternative preparedness measures for both technological accidents and terrorist threats/sabotage against Swedish nuclear facilities. This work was carried out in 8 workshops held in Stockholm during a six month period in 2002-2003. SKI participated in the workshops with 6-7 subject specialists, who developed the laboratories with the help of two senior morphologists from FOI.

In studies of this type, it is advantageous to develop two complementary morphological fields or laboratories: e.g. one which systematically maps out ranges of possible *scenarios*, based on factors which cannot be directly controlled and which put demands on the organisation in question (i.e. an "external world" field); and one in which we map out alternative *strategies,* depending on variables which can, more or less, be controlled by the organisation (i.e. an "internal world" or strategy field). These two fields can then be linked (by internal cross-consistency assessments) in order to establish which strategies would be most effective and flexible for different ranges of scenarios. In fact, three morphological fields we developed for the SKI-study: 1) a dedicated *threat scenario laboratory*; 2) a field to map out the *demands* different scenarios would place on SKI preparedness; and 3) a *preparedness resource* field.

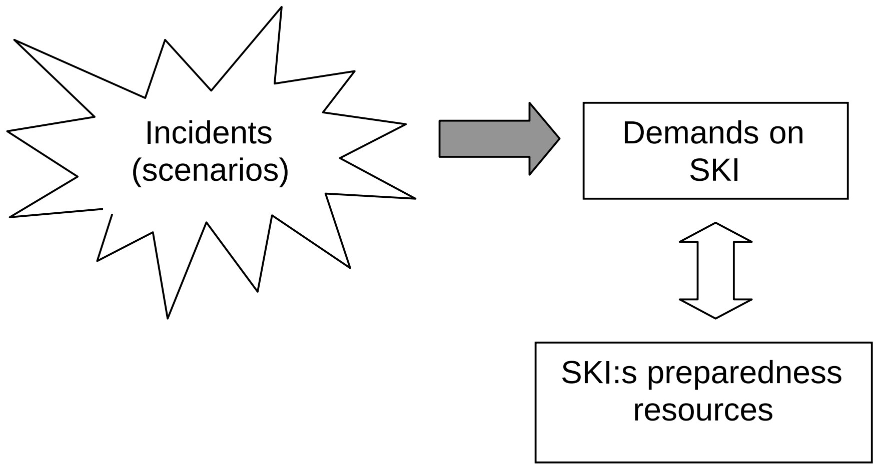


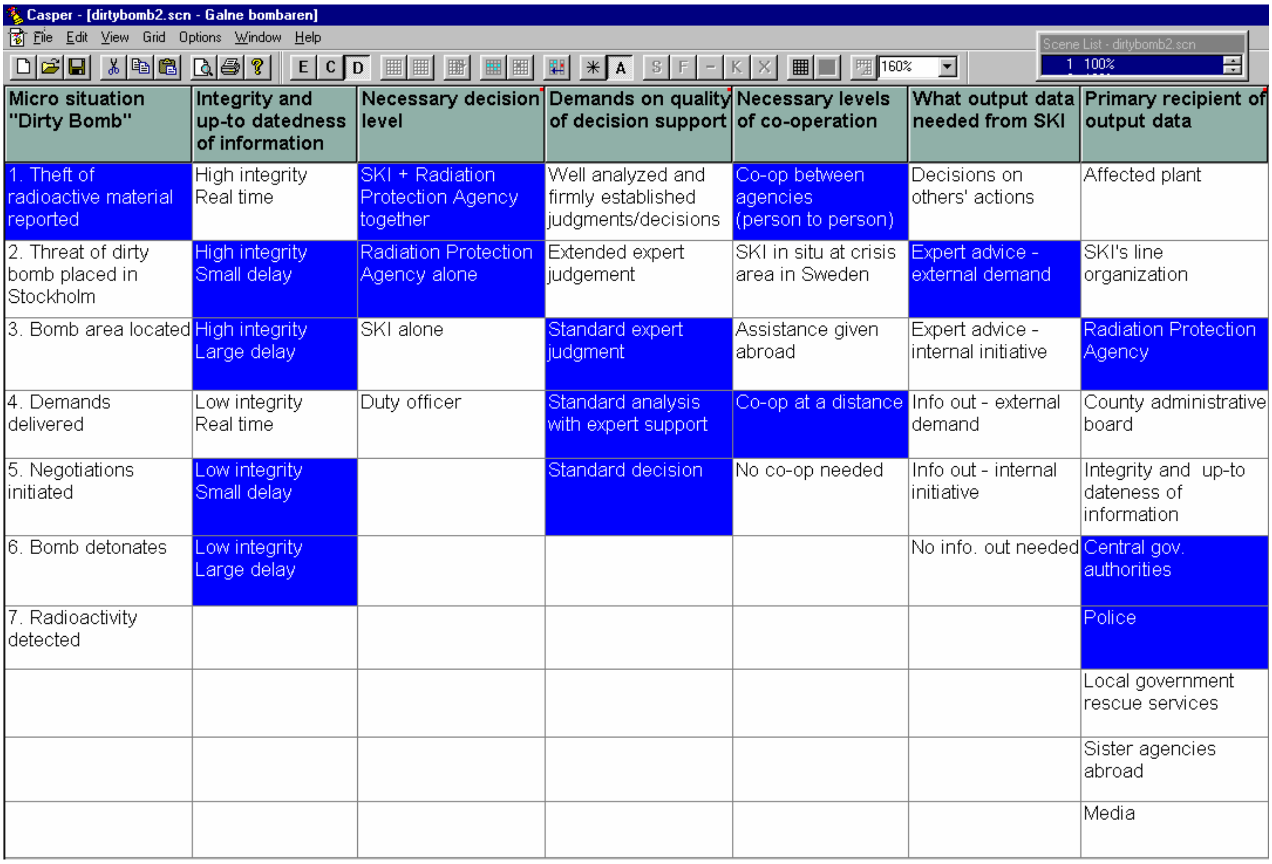
Figure 1: Model for structuring SKI preparedness for extended threat spectrum

We have found that it is usually best to begin with the scenario fields, since this will provide a framework for later identifying relevant demands and strategy variables. One of the dedicated *threat scenario fields* is presented in Stig Isaksson's paper – "Protection against Sabotage of Nuclear Facilities: Using Morphological Analysis in Revising the Design Basis Threat", also given at this conference. Such *scenario fields* can generate tens of thousands of possible threat scenarios.

Figures 2 and 3 (following page) show segments of two of the fields developed in response to the threat scenarios derived from the scenario fields. Figure 3 is a "situation demand-field" linked to a "dirty bomb" scenario (first column). The scenario is divided into seven phases in order to give a time-line for demands placed on SKI. The configuration cluster shown here is for the first time-step in the scenario: "Theft of radioactive material reported".

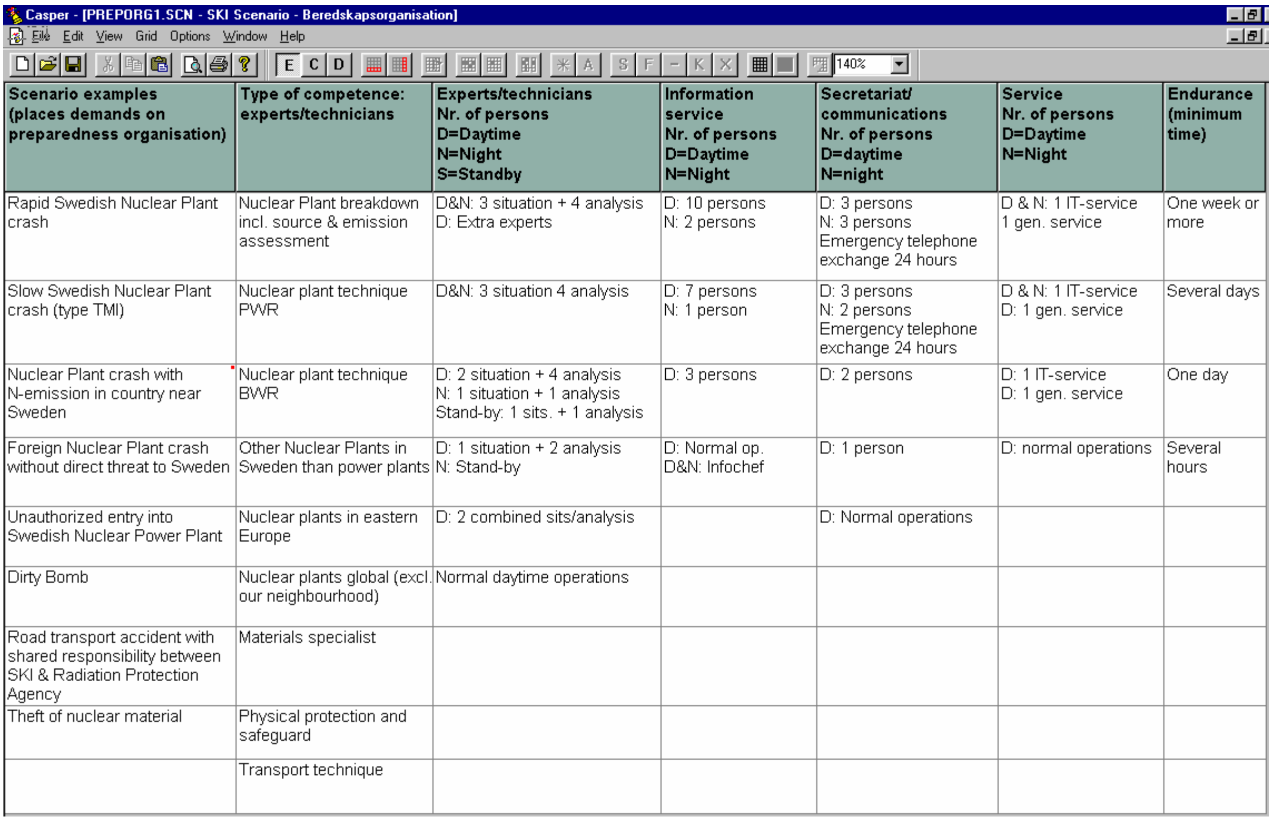
Figure 4 pits eight integrated scenarios (each of which has its own internal time-line) against a number of parameters describing SKI's possible preparedness resources. The working group steps through each scenario and time-line, in order to assess realistic resource-needs in response to the scenarios and demands that they entail.

Note that these fields are not intended to be the "final word" in the study – they do not represent "the truth" -- but are frameworks for facilitating round table discussions, education, training and gaming. Also, the very process of developing these fields is, in itself, an important learning experience for the working groups involved.



Micro situation "Dirty Bomb"	Integrity and up-to datedness of information	Necessary decision level	Demands on quality of decision support	Necessary levels of co-operation	What output data needed from SKI	Primary recipient of output data
1. Theft of radioactive material reported	High integrity Real time	SKI + Radiation Protection Agency together	Well analyzed and firmly established judgments/decisions	Co-op between agencies (person to person)	Decisions on others' actions	Affected plant
2. Threat of dirty bomb placed in Stockholm	High integrity Small delay	Radiation Protection Agency alone	Extended expert judgement	SKI in situ at crisis area in Sweden	Expert advice - external demand	SKI's line organization
3. Bomb area located	High integrity Large delay	SKI alone	Standard expert judgment	Assistance given abroad	Expert advice - internal initiative	Radiation Protection Agency
4. Demands delivered	Low integrity Real time	Duty officer	Standard analysis with expert support	Co-op at a distance	Info out - external demand	County administrative board
5. Negotiations initiated	Low integrity Small delay		Standard decision	No co-op needed	Info out - internal initiative	Integrity and up-to dateness of information
6. Bomb detonates	Low integrity Large delay				No info. out needed	Central gov. authorities
7. Radioactivity detected						Police
						Local government rescue services
						Sister agencies abroad
						Media

Figure 2: Segment of the "demand-field" linked to a "dirty bomb" scenario. The configuration cluster shown here is for the first time-step in the scenario: "Theft of radioactive material reported".



Scenario examples (places demands on preparedness organisation)	Type of competence: experts/technicians	Experts/technicians Nr. of persons D=Daytime N=Night S=Standby	Information service Nr. of persons D=Daytime N=Night	Secretariat/ communications Nr. of persons D=daytime N=night	Service Nr. of persons D=Daytime N=Night	Endurance (minimum time)
Rapid Swedish Nuclear Plant crash	Nuclear Plant breakdown incl. source & emission assessment	D&N: 3 situation + 4 analysis D: Extra experts	D: 10 persons N: 2 persons	D: 3 persons N: 3 persons Emergency telephone exchange 24 hours	D & N: 1 IT-service 1 gen. service	One week or more
Slow Swedish Nuclear Plant crash (type TMI)	Nuclear plant technique PWR	D&N: 3 situation 4 analysis	D: 7 persons N: 1 person	D: 3 persons N: 2 persons Emergency telephone exchange 24 hours	D & N: 1 IT-service D: 1 gen. service	Several days
Nuclear Plant crash with N-emission in country near Sweden	Nuclear plant technique BWR	D: 2 situation + 4 analysis N: 1 situation + 1 analysis Stand-by: 1 sits. + 1 analysis	D: 3 persons	D: 2 persons	D: 1 IT-service D: 1 gen. service	One day
Foreign Nuclear Plant crash without direct threat to Sweden	Other Nuclear Plants in Sweden than power plants	D: 1 situation + 2 analysis N: Stand-by	D: Normal op. D&N: Infochef	D: 1 person	D: normal operations	Several hours
Unauthorized entry into Swedish Nuclear Power Plant	Nuclear plants in eastern Europe	D: 2 combined sits/analysis		D: Normal operations		
Dirty Bomb	Nuclear plants global (excl. our neighbourhood)	Normal daytime operations				
Road transport accident with shared responsibility between SKI & Radiation Protection Agency	Materials specialist					
Theft of nuclear material	Physical protection and safeguard					
	Transport technique					

Figure 3: Scenarios linked to preparedness resource field.

CONCLUSIONS

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

Of course, as is the case with everything else, the output of any analysis-synthesis cycle is no better than the quality of its input. However, even here the morphological approach has some advantages. It expressly provides for a good deal of in-built "garbage detection", since poorly defined parameters and incomplete ranges of conditions are immediately revealed when one begins the task of synthesizing solutions and checking these for internal consistency.

From a nuclear regulatory perspective, morphological analysis and the MA/Casper system has shown itself to be an excellent tool for developing a threat scenario laboratory and for revising preparedness planning. Additionally, both the process and the results of the study are well documented, transparent and traceable.

Further articles on morphological analysis can be downloaded from:
www.swemorph.com

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