Modelling Complex Socio-Technical Systems Using Morphological Analysis

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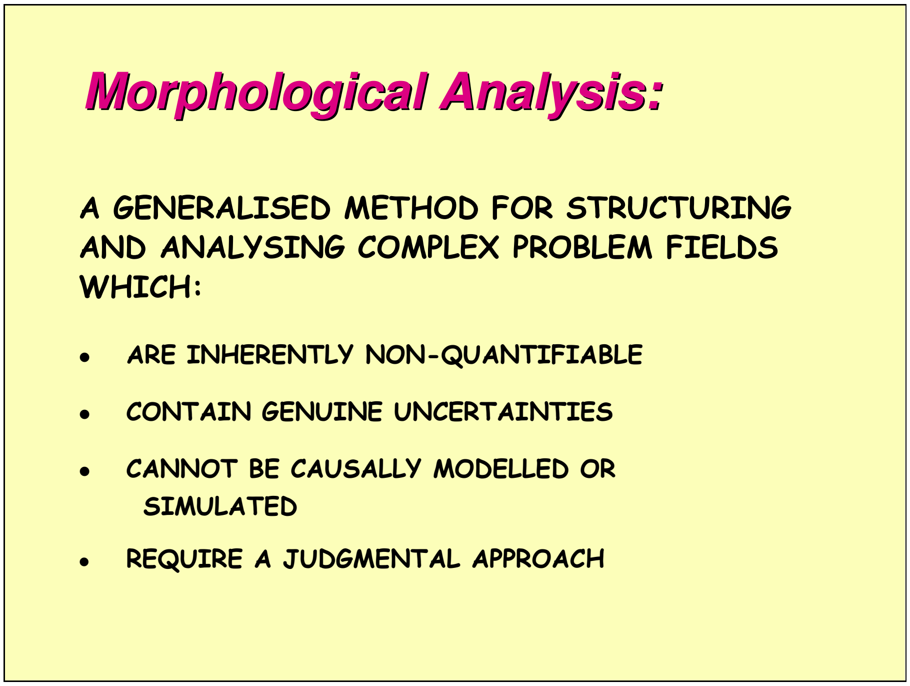
For the past 15 years, we have carried out research in non-quantified modelling, with special emphasis on a method called general morphological analysis (GMA). To date, we have employed this modelling method in some 100 projects, involving policy analysis, scenario development and strategy management.

What is general morphological analysis? The term *morphology* comes from classical Greek (*morphe*) and means *shape* or *form*. Thus morphology is the study of the shape and arrangement of parts of an object, and how these parts "conform" to create a whole or Gestalt. The "objects" in question can be physical objects (e.g. an organism, an anatomy, a geography or an ecology) or mental objects (e.g. word forms, concepts or systems of ideas).

Specific forms of morphological analysis are used in a number of scientific disciplines – for instance, linguistics, zoology and geology – in which formal, structural relationships are more important than quantity as such. However, what I am presenting today is “general morphology” – i.e. morphological analysis that is not associated with any specific discipline.

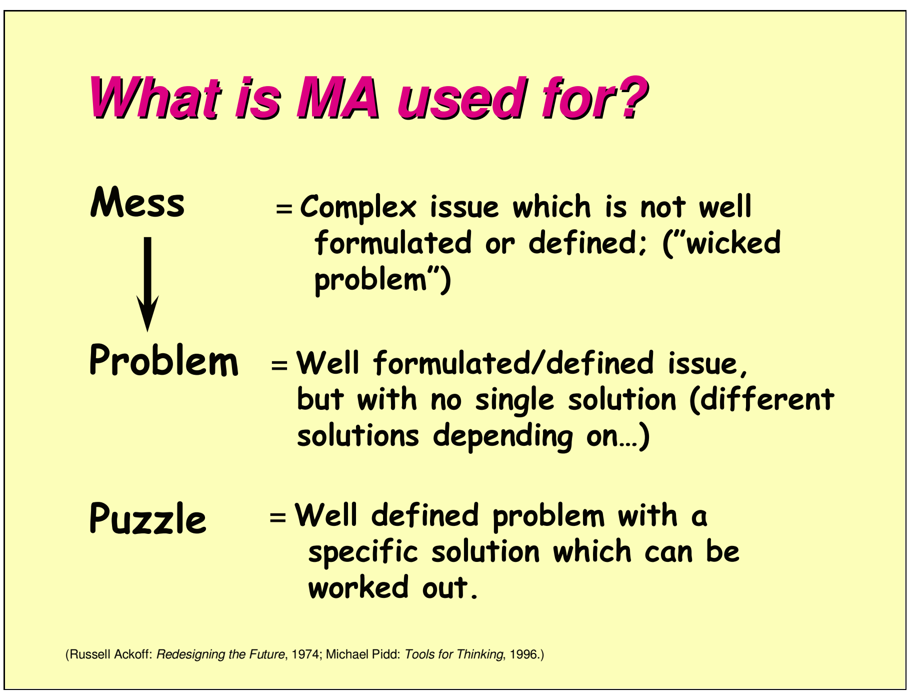
The research program, which was initiated in the early 1990's, was aimed at developing a methodological framework for creating models of systems and processes, which cannot be meaningfully quantified. With this in mind, we began by attempting to develop an extended form of what is called *typology analysis* (see below). Initially, we thought we were doing something new. However, we subsequently learned that extended typology analysis was invented as early as the 1930’s by Fritz Zwicky, professor of astronomy at the California Institute of Technology – the famous Caltech in Pasadena.

Most of you have probably never heard of Zwicky, but forty years ago he was a well-known scientific personality. He coined the term *supernova*, was the first to hypothesize the existence of *neutron stars*, and is regarded by many as being the father of the modern jet engine. He developed a general form of morphological analysis in order – among other things – to categorize and hypothesize new types of astrophysical objects, to develop jet and rocket propulsion systems, and to study the legal aspects of space travel.



Slide 1

MA is a general method for structuring and analysing complex problem fields which 1) are inherently non-quantifiable; 2) contain non-resolvable uncertainties (both antagonistic and non-specified uncertainty); and 3) cannot be causally modelled or simulated in a meaningful way. Instead, a judgemental approach must be taken. The question is: can we put a judgemental approach – carried out in groups of subject specialists -- on a sound methodological and scientific basis? We think that this can be done with the non-quantified, but highly structured method of morphological analysis.



Slide 2: Messes, problems and puzzles

Messes, problems and puzzles

Before going into morphological analysis as such, it is a good idea to discuss what MA is good for, and what it is *not* good for. In his book from 1974 titled "Redesigning the Future", the operational analyst Russell Ackoff defined three levels of complex problems.

The first level he called a *mess* (also known as a “wicked problem” (Ritchey, 2005)). A *mess* is a complex issue, which does not yet have a well-defined form or structure. When you have a mess, you don’t even know for sure what the problem is yet. Here is an example of a mess, that our National Rescue Services Agency asked us to help with some years ago: *What are we going to do with the Swedish bomb shelter programme now that the cold war has ended*? This is complex issue which concerns money, technology, ethics, politics, everything! And all of these different aspects must be treated together –and dealt with as a whole.

All of the really important issues in the world start out as *messes*. And all of us come into contact with messes on a daily basis.

The next level is what Ackoff calls a *problem*. This is an issue that does have a defined form or structure; it is dimensioned; it has variables and we know something about how these variables interact. But it does not have any one, single, clear-cut solution. As long it is a problem – in Ackoff’s use of the term – it has many different, alternative solutions “depending on”. Depending on, for example: how much money we have; what type of technology is going to be available; who is in political power; what the weather is going to be like? Since we may not know these things yet, we have to leave the problem's solution open to different hypotheses about how the future might turn out.

The last level is called a *puzzle*. A puzzle is a well-defined and well-structured problem with a specific solution that somebody can work out.

Morphological analysis was explicitly developed to work at the level of messes and problems. More specifically, MA is used to turn messes *into* (structured) problems. In the process, we build up a problem laboratory where we can generate alternative solutions *depending on different hypothesized conditions*. In a sense, we build a non-quantified input-output model, in which we can define independent and dependent variables, test certain conditions against others, and hypothesize relationships.

The relationship between messes, problems and puzzles is summed up beautifully by Michael Pidd in his book "Tools for thinking" (1996. p 40):

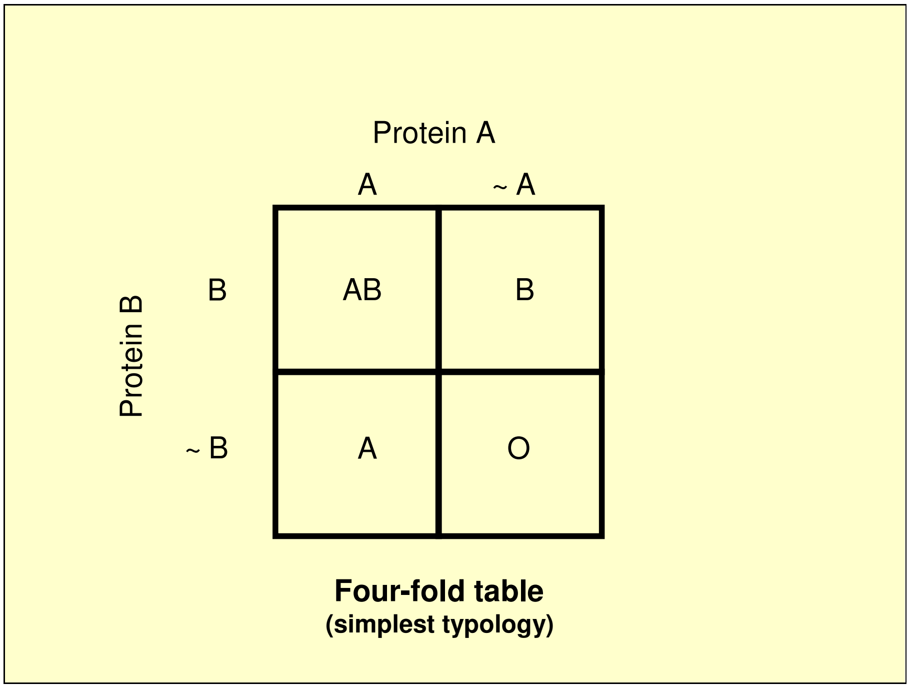
> “One of the greatest mistakes that can be made when dealing with a mess is to carve off part of the mess, treat it as a problem and then solve it as a puzzle -- ignoring its links with other aspects of the mess.”

This type of mistake is made all the time, because we humans do not like to be confronted with messes for any length of time. Inherently, we are puzzle solvers. We want to get out of the mess as quickly as possible. However, this can have dreadful consequences.

When we do a morphological analysis, we want to examine the *whole mess* first, stalk out its boundary values and study its possible internal relations – before going on to generate alternative solutions, and then to solve puzzles.

Typologies and morphologies

Slide 3 (below) is an example of a so-called *fourfold table*. When you have two simple variables – each variable expressible in two ways, e.g. yes or no – you put them together in a fourfold table and check out the possible combinations they produce. This is a fourfold table for Landsteiner's ABO blood-type system. In this system, you either have base substance A in your blood or not, AND you either have base substance B or not. Four possible blood types are thus defined -- or hypothesized. At one extreme, if neither A nor B is present, you have blood type 0, the universal donor. At the other extreme, if both are present, you have type AB – the universal receiver.

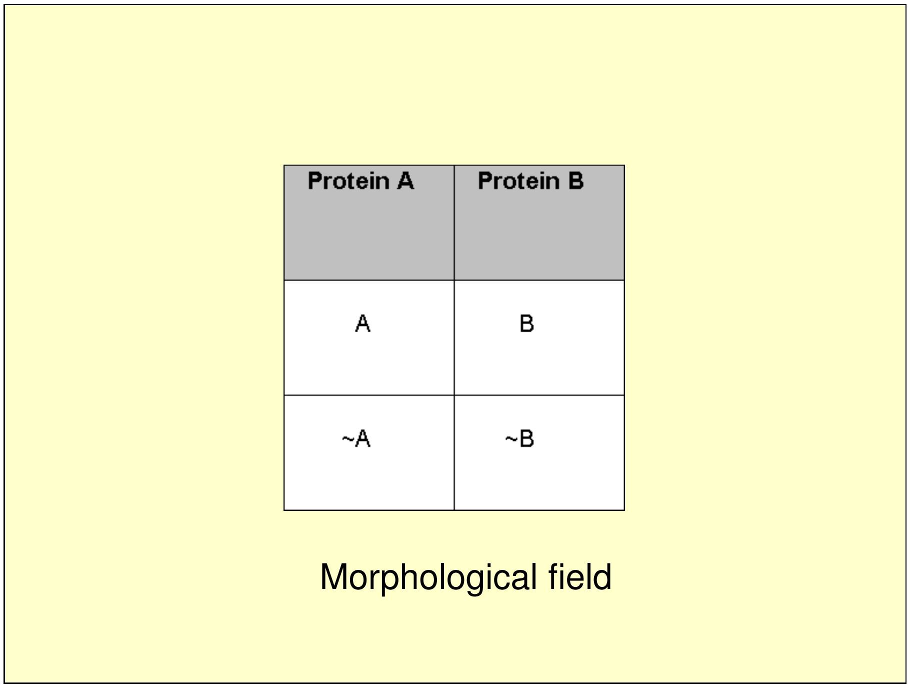


Slide 3: Four-fold table (ABO-system)

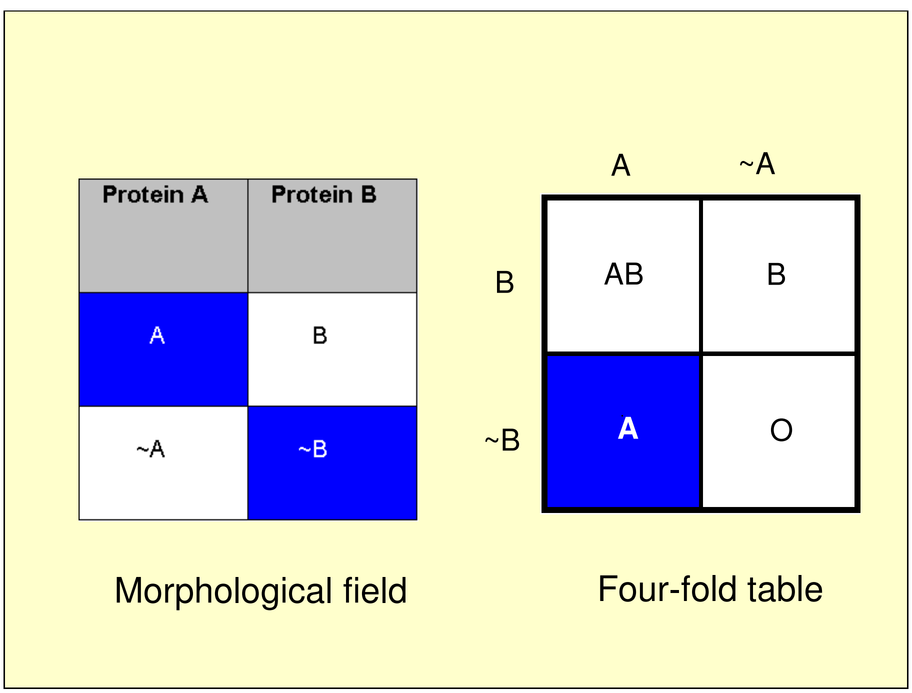
A four-fold table of this kind is the simplest form of a *typology*. A typology is a simple model based on the possible combinations obtained between two or more variables, each variable containing a (finite) range of discrete values or conditions. Each of the possible combinations of variable-values is called a *constructed type*.

Observe a few things about this typology. Like a little Cartesian co-ordinate system, it utilises (two) spatial dimensions – height and breadth – to represent the ranges of the two variables. A typology of this sort is the simplest possible form of a model. You may not think of it as a model, but it is. It has inputs and outputs; and it gives you the possibility to hypothesize relationships and generate theory.

Slide 4 (below) represents the same model, but in the form of a morphological field instead. In a morphological field, you put your variables up at the top of the columns, and list their values underneath. So, in Slide 5 (below), we see two fully equivalent models of the ABO-system, with equivalent representations of blood type A.



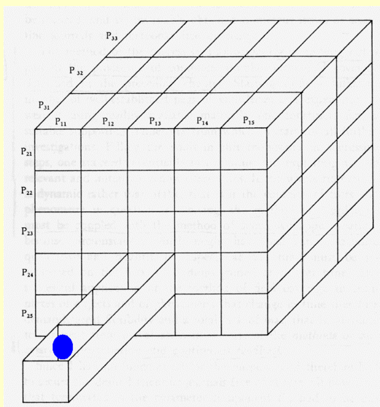
Slide 4: Simplest morphological field



Slide 5: Equivalent field configurations

But here is the point: As long as you are only working with two variables, typologies are fine. But what if you want to work with more than two variables? Remember: classical typologies use spatial dimensions to represent its ranges of values. What happens if you want a three-variable model?

The three-dimensional typological field on the left side of Slide 6 (below) is called a Zwicky box. Zwicky used it to demonstrate the advantages of morphological fields over classical typological fields. On the right is the corresponding, three-dimensional morphological field. Note that the blue cells in the morphological field represent the blue point on the x-, y- and z-axes in the typological box.



Zwicky Box

Parameter X	Parameter Y	Parameter Z
X1	Y1	Z1
X2	Y2	Z2
X3	Y3	Z3
X4	Y4	
X5	Y5	

3-dim morphological field

Slide 6: Three-dimensional configuration spaces

Four-dimensional fields (employing so-called embedded variables) are used in typology construction, but this is about the effective limit. However, morphological fields are not constrained by spatial dimensions, and are thus not limited to three or fours variables.

At FOI, we work with morphological fields of up to a dozen dimensions, which may define hundreds of thousand, or millions, of different constructed types or configurations.

Fritz Zwicky worked in the 1930's, 40's and 50's when there were no modern computers. He died in 1974 and general morphology more or less died with him. Today, fast, small computers with advanced graphic interfaces have revolutionised morphological analysis. Now, with computer support, we can develop complex, non-quantified models and scrutinize the many thousands of relationships in a timeframe that was impossible for Zwicky.

Morphological analysis as a process of collective creativity

We use MA primarily for developing scenario and strategy laboratories, for structuring and analysing policy spaces and for relating means and ends in operational planning. It is also excellent for carrying out so-called positional or stakeholder analysis – which we feel is a necessary complement to cost-benefit analysis. Our clients include Swedish Total Defence authorities, Swedish EPA and Ministry of the Environment, the National Rescue Services, the International Aid and Development Agency (SIDA), the Center for Science, Policy, and Outcomes (CSPO - Washington DC), and a number of international academic and non-governmental organisations.

For our part, we developed computer support for morphological analysis – the so-called MA/Casper system – with the following conditions in mind:

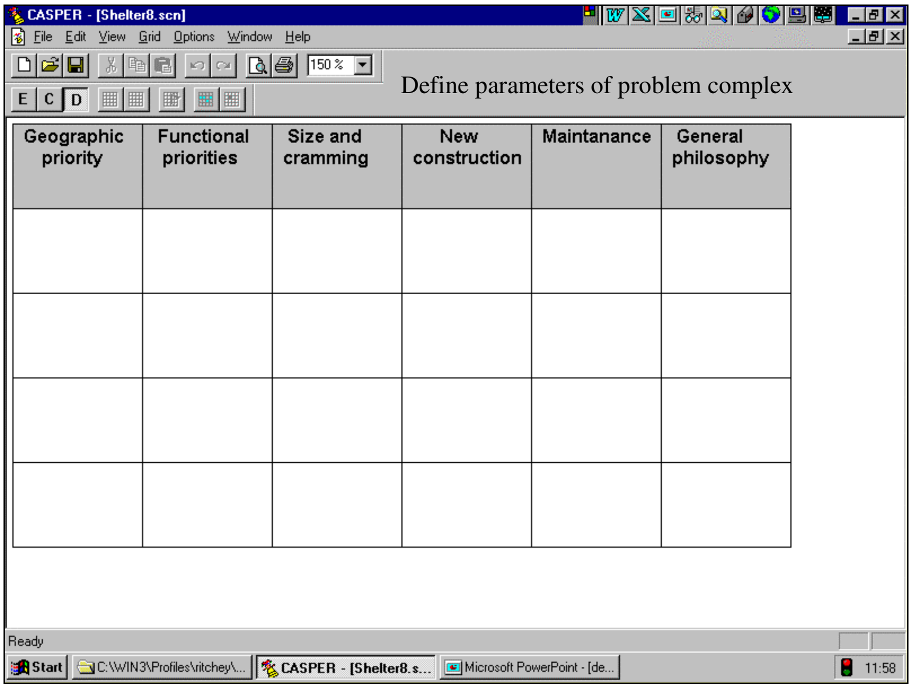
1. *The method should be process and group oriented.* In other words, it is the process that the subject-specialist group goes through in doing morphology that is the most important result, not what comes out of the computer.
2. *It should be generic.* MA is a general method for non-quantified modelling. It sets no specific preconditions on the working group. You start with a blank slate, and the group successively builds up a non-quantified model.
3. *It should be transparent.* There are no black boxes. All the cards are on the table. You cannot hide anything. Another way of saying this is:
4. *It should leave an audit trail.* You should be able to trace what you have done and how you have come to your conclusions. Although judgemental processes will never be as traceable as, for example, a mathematical proof, MA allows for as much traceability as is possible under such circumstances.
5. *It should be easy to update.* If we work with a complex problem area, and come back to our client a year later, and somebody says .. “a new dimension or variable has become important” .., we can build this new parameter into the prior work, without having to start from scratch.

How, then, does one carry out a morphological analysis? First, you have to have a mess to work with. The example that I am going to use for this presentation is the "bomb shelter mess" I mentioned earlier – i.e.: *What are we going to do with the Swedish bomb shelter programme, now that the cold war is over?*

The second thing you need is a small group of subject specialists -- no more than 5-7 people. Ideally, the group should be heterogeneous, representing different aspects of the issue involved. In the “shelter group”, we engaged people representing financial, technical, political, military, security policy and ethical aspects of the issue.

A morphological analysis is carried out in a number of iterative steps, in which the subject-specialist group goes through a number of analysis-synthesis cycles. The time needed for such a study depends on a number of factors: the severity of the "mess", the level of ambition, extent of coverage and/or resolution, the desired end-result, etc. For instance, the end-result can vary between simply structuring the problem field, to developing a expert validated, non-quantified input-output model.

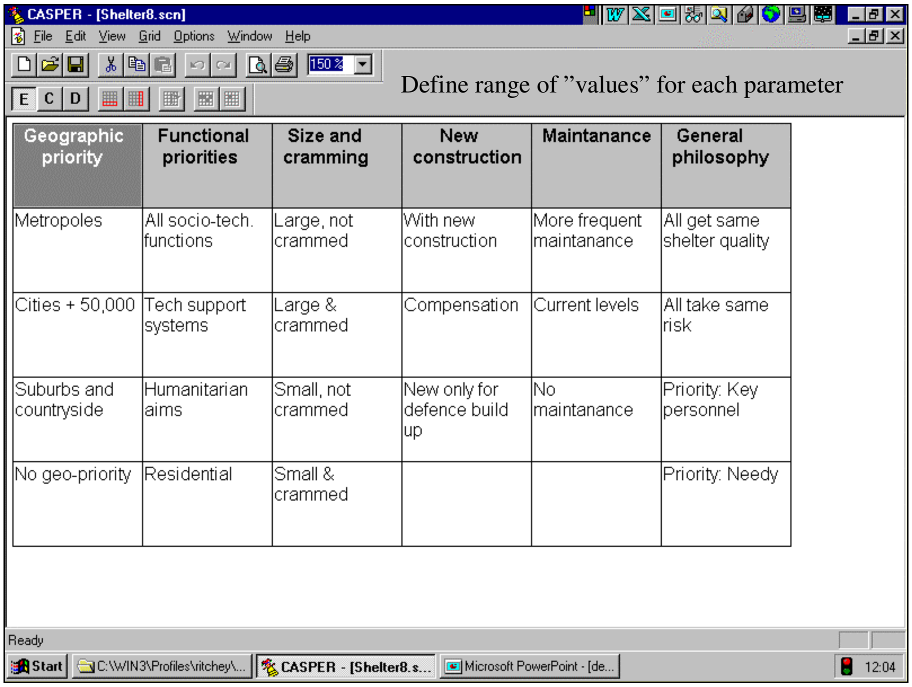
The first step (Slide 7) is to define the primary parameters of the problem complex. For instance, concerning the shelter issue: *Where* are we going to build shelters? *Who* and *what* do we actually shelter? *Size* and *degree* of cramming? What are we going to do with *new construction* and *maintenance*? Finally, what is the *general philosophy* behind the bomb shelter programme? (This is only a segment of one of the fields developed in the shelter study. We use it only as a pedagogic example.)



Slide 7: Define important dimensions of problem complex

Defining the 6-8 primary parameters of a problem complex may seem relatively simple, but in fact is a difficult and fascinating task. We have carried out some 80 projects in morphology during the last 10 years, and have learned that it takes considerable time and a lot of discussion to agree upon the most important variables. However, 6-8 parameters – if chosen and moulded carefully – suffice to get a good grip on even the most complex problem areas. If you want more detailed coverage, more parameters can be added later. However, there is no such thing as 100% coverage. Reality presents us with infinite dimensionality. We are working with *models* of reality, which are never complete.

The second step (slide 8, below): For each parameter, define a spectrum of *values* – or what we call *conditions* – which represent alternative solutions to the particular issue that the parameter expresses. Sometimes this is a scale, as in “Geographical priority”; sometimes a complex binary combination such as “Size and degree of cramming”; sometimes small scenarios or idea-packages such as the four points under “Shelter philosophy”. If you are working with a scale, start with the boundary values. In general, it is good practice to draw out the boundaries of the parameters as far as possible, and attempt to define the extreme limits of each variable. (Things that you think are extreme or silly now, have a habit of turning into reality tomorrow.)



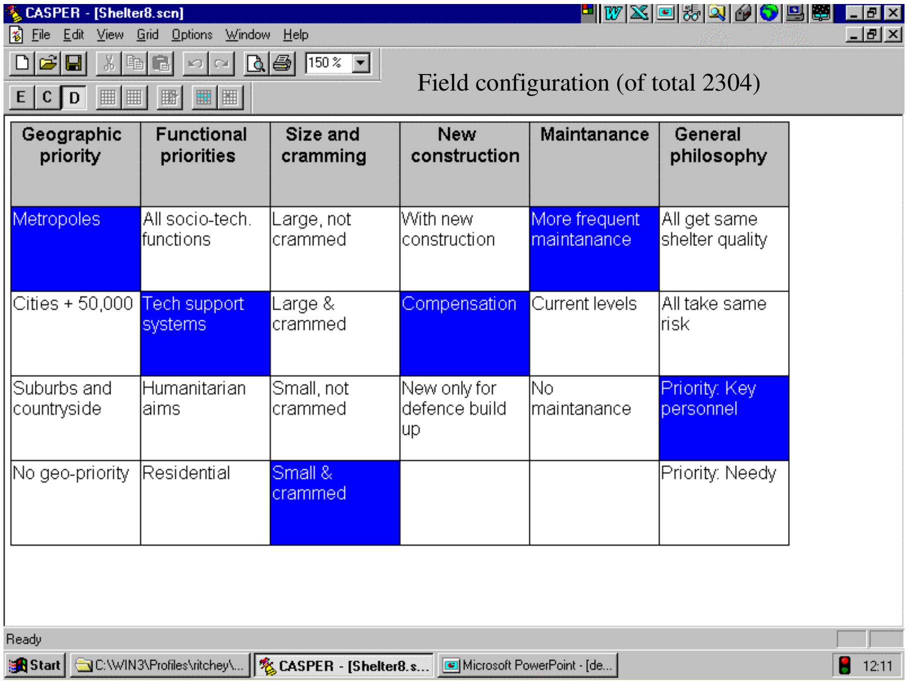
Geographic priority	Functional priorities	Size and cramming	New construction	Maintanance	General philosophy
Metropoles	All socio-tech. functions	Large, not crammed	With new construction	More frequent maintanance	All get same shelter quality
Cities + 50,000	Tech support systems	Large & crammed	Compensation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

Slide 8: Proto morphological field

The totality of the parameters and their respective values is a *morphological field*. When you get a good field defined, the working group is really happy, because this represents your problem universe. It might be six variables or eight or ten. It is good to keep the field relatively small at the beginning. You can always expand it later.

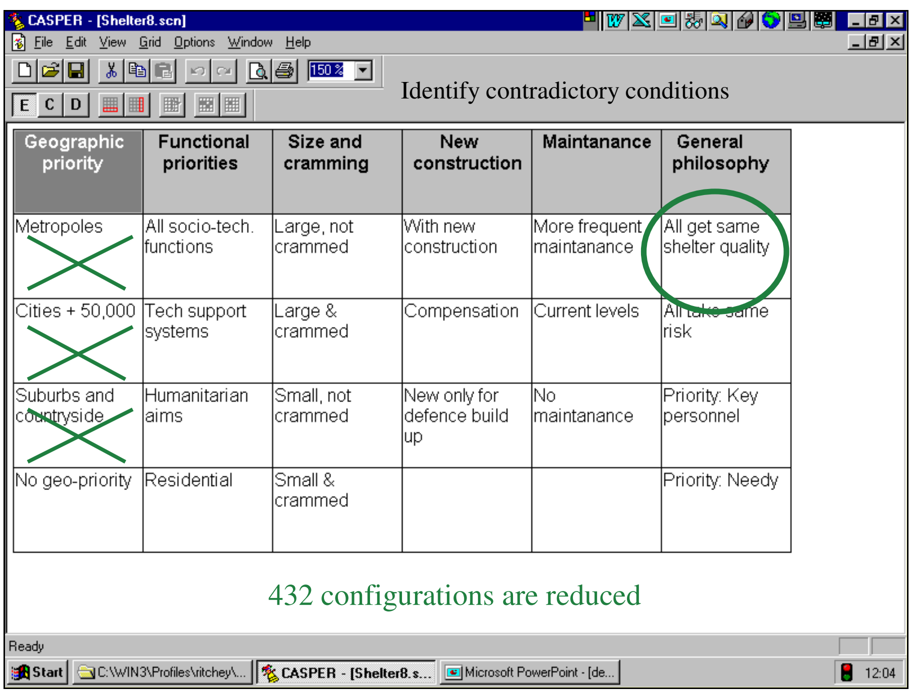
There is an enormous amount of potential information in a well-developed morphological field, especially as concerns how the different parameter conditions are related to one another. Remember, this is not a table. It is a multi-dimensional configuration space. Within this space, we want to start defining configurations (corresponding to *constructed types* in a typology) -- that is, combinations of conditions, which represent different formal solutions to the problem complex. Slide 9 (next page) is one such formal solution.

How many solutions or configurations are there in a morphological field? This is easy to calculate: simply multiply together the number of conditions under each parameter. In this case 4x4x4x3x3x4 = 2,304 possible configurations. This is a relatively small field. Normally, when we work with 8-10 parameter fields, we may have millions of possible configurations. The point is, that there are far too many to look at and check by hand. Somehow, we must be able to reduce the number of configurations in a field, so that *only those that meet certain criteria remain*. The main criterion is, that a configuration is internally consistent, i.e. that is does not contain conditions that are mutually contradictory.



Slide 9: Single field configuration of 2304 possible

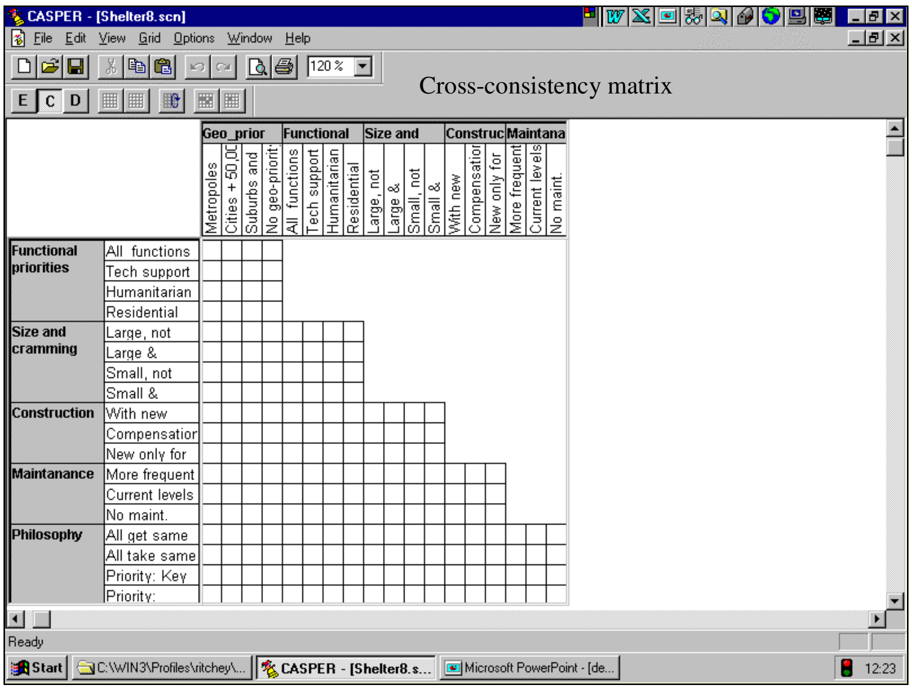
Take a look at Slide 10 (below). If everyone is going to have the "same shelter quality", then you cannot have any "geographical priority". This is a contradiction in terms. Thus any and all configurations that contain any of the marked pairs of conditions can simply be thrown out, since they are internally inconsistent. In this case, the field is reduced by 432 configurations, c. a fifth of the total number of formal configurations.



Slide 10: Contradictory parameter values

Classical morphological fields are full of contradictions, both logical and empirical, which must be identified and weeded out. In fact, most morphological fields can be reduced by up to 90 or even 99 percent. This reduction leaves us with a manageable number of configurations – i.e. solutions – to examine and work with.

How do you reduce the field? You do this by comparing each condition with every other condition, and asking the question: Can these two conditions coexist? This is done by way of a cross-consistency assessment, with the help of a cross-consistency matrix (Slide 11).



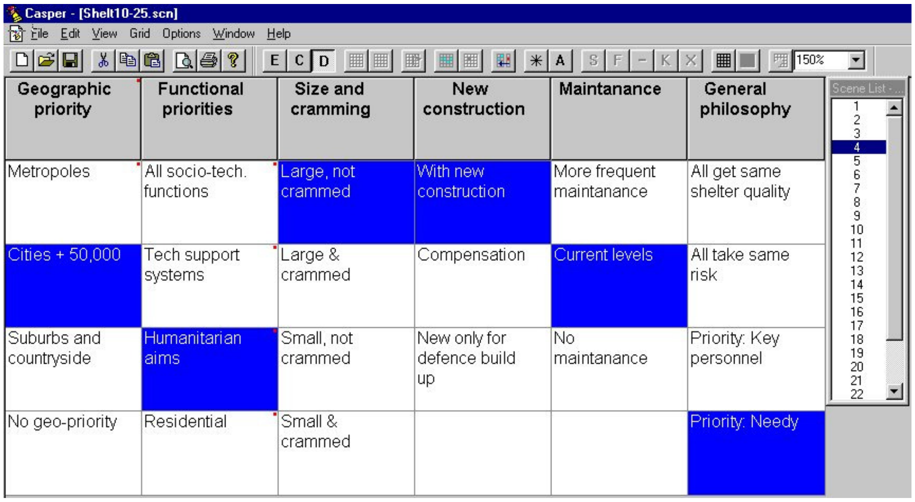
Slide 11: Cross-consistency matrix

The cross-consistency assessment accomplishes three things. Firstly, it functions as a garbage detector. The garbage it detects is in the form of vague concepts; concepts with different meanings for different participants; different terms meaning the same thing, etc. When these are revealed – and they absolutely will be revealed when you put them to the test of a cross-consistency-assessment – then you must go back to the morphological field and review the concepts, redefining, adding and subtracting parameters and conditions as needed. When everyone is in agreement about what the content of all the cells in the field mean, and the cross-consistency assessment starts working, then you have an acceptable prototype field.

Secondly, the cross-consistency assessment represents a deep dive into the problem complex. Everyone working through the field in this way learns something new – since the whole point is to relate different aspects of the problem complex to each other. No one has a total mastery of the type of complex problem fields we usually work with. The cross-consistency assessment forces a dialogue between different areas of knowledge.

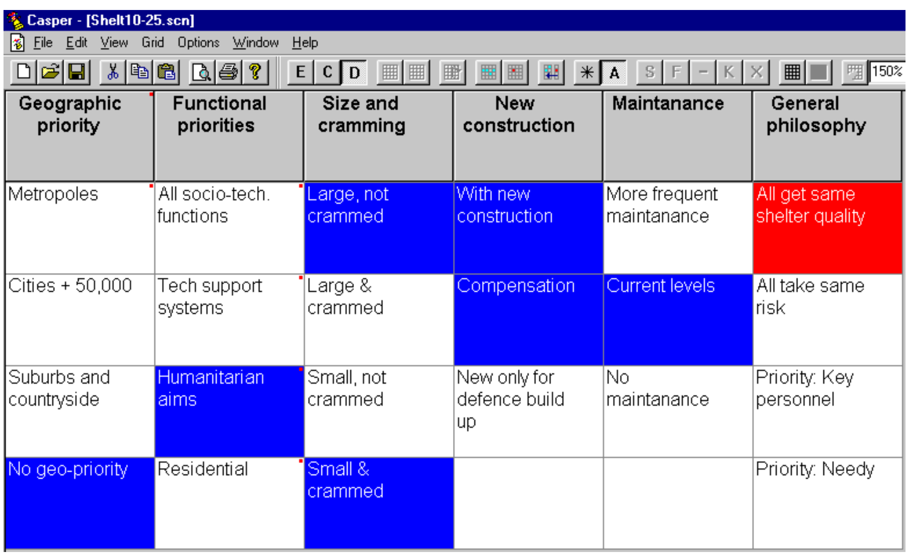
Finally, when you have completed the assessment, the morphological field is ready to be reduced. We execute a function in the software developed to support morphological analysis, and the computer does in a matter of seconds, that which took Fritz Zwicky weeks to do by hand. The field is reduced and we are left with a list of the surviving configurations. This list represents the *solution space* of this particular problem complex.

(Note that the cross-consistency matrix can be changed and recalculated, in order to perform a sensitivity analysis.)



Slide 12: One configuration of solution space

In this case, with our "bomb shelter exercise", we are left with 125 solutions out of the original 2304 formal configurations (Slide 12). We could go right down the list and look at one after the other. However, with computer support, we can do much more. For instance, we can define any particular variable as a driver, or even select several variables as multiple drivers.



Slide 13: Solution space (blue) with single driver (red)

For example: If you want to see all the solutions that include the condition "Everyone gets the same shelter quality", we can treat this particular condition as an "input" by locking it, and obtain a resultant outcome space (Slide 13, previous page). In a morphological field, any parameter can serve as a *driver* (or "independent variable); anything can be input and anything can be output.

This field segment was presented as an exercise only. Let's take a look at something more complex.

MA-projects typically involve developing conceptual laboratories, which allow us to relate (external) scenario fields to (internal) strategy alternatives. We have developed such laboratories, *inter alia*, as instruments for generating threat scenarios for the Swedish National Defence; for identifying alternative long-term social evolutionary trends for the Swedish Nuclear Waste Management agency; and for evaluating risk (including terrorist threats) and alternative preparedness measures for the Swedish Nuclear Power Inspectorate and the Radiation Protection Agency.

We have found MA especially suitable in the area of environmental policy studies, in which different environmental strategies can be pitted against a range of possible futures scenarios. A case in point is a study done for the Ministry of the Environment concerning the development of an E*xtended Producer Responsibility* system in Sweden.

Extended producer responsibility (EPR) imposes accountability over the entire life cycle of products and packaging introduced on the market. This means that firms, which manufacture, import and/or sell products and packaging, are required to be financially or physically responsible for such products after their useful life cycle. They must either take back spent products and manage them through reuse, recycling or in energy production, or delegate this responsibility to a third party -- a so-called producer responsibility organization (PRO), which is paid by the producer for spent-product management.

In studies of this type, it is advantageous to develop two complementary morphological fields: one in which we can systematically develop different EPR *strategies,* depending on variables which can be more or less controlled (i.e. an "internal world" field); and the systematic development of a number of different possible futures scenarios based on factors which cannot be directly controlled by those developing the EPR-system (i.e. an "external world" field). Both of these fields are assessed for internal cross-consistency, and then linked to each other by cross-consistency assessments, in order to establish which strategies would be most effective and flexible for different ranges of scenarios.

Slide 14 (below) is one of the fields developed for the EPR study. It represents a scenario matrix linked to three strategy alternatives developed from a strategy matrix. In this example, eight scenarios are defined which cover a wide range of global possibilities (listed in the first parameter on the far left). The three strategy alternatives (listed on the far right) were linked by cross-consistency assessments to each of the attributes in the scenario field. A forth strategy alternative -- "No strategy available" -- represents the case in which none of the three given strategies measures up to the demands of a given scenario.

SCENARIO	Buyer behavior	Consumption patterns T=total cons. P= private import	Consumer sorting behavior (trends)	National environmental policy	Price of new raw material vs reclaimed material	Production technology: volume of materials required	Technology development: reclaiming technology	EU-directives for import and export of waste	Producer responsibility strategy
Wild, Wild East	Willing to pay more for green products	T: Up P: Up	Voluntary (ideologically driven)	At the forefront; Holistic approach (Legal & econ.)	New: High Reclaimed: High	Much less than today	Very rapid increases	Less restricted than today	STRATEGY A
Raw Mat Depletion	Will to buy green, but will not pay more	T: Status Quo P: Up	Will sort for compensation/ reward	At forefront, but no holistic approach (only legal)	New: High Reclaimed: Low	Somewhat less than today	Substantial increases	Same as today	STRATEGY B
Current policies (Negative trend)	No interest in buying green products	T: Up P: Status Quo	Will sort if facing sanctions	Ideological, based on voluntary acceptance	New: Low Reclaimed: High	Same as today	Only marginal increases	More restrictive than today	STRATEGY C
Current policies (Positive trend)		T: Status Quo P: Status Quo	Will resist sorting	Least possible adaptation	New: Low Reclaimed: Low				NO STRATAGY AVAILABLE
Green-house effect (Stop emissions)									
Batman: High-tech solutions									
Dematerialized production (New materials)									
Green market (ideological paradise)									

Slide 14: A scenario-strategy matrix for Extended Producer Responsibility study

Here, strategy B is shown to be able to cope with 3 of the 8 hypothesised scenarios, whereas there is no strategy available to cope with 2 of the scenarios (light blue).

Finally, the example in Slide 15 (below) is a segment of one of the fields developed in a study done for the Swedish Agency for Economic Crime and a number of other law enforcement organisations. We wanted to look at the complex structure of economic crime and relate this to different methods of mitigation. This was a real mess: economic crime concerns everything from me cheating on my income tax, to organised drug trafficking, to state-led international economic sabotage.

Victim	Type of crime (10 general examples)	Method	Types of solutions available	Legislation	Influence motives
Consumer	Cheating on taxes/ tolls etc.	False information to official	Physical/visible controls	Standard regulations	Influence goal
External environment	Environmental crimes	Physical handling	Technical solutions	Order regulations	Influence means
Competitors	Fraud against companies	Bookkeeping	Administrative controls	Permission regulation	Reward
Employees	Crimes to reduce costs	Financial transactions	System and organisational solutions	Proceeding regulations	Sanction
Financers	Limiting competition	International IT- transactions	NONE	NONE	NONE
Owners	Cheating with subsidies	Planned bankruptcy			
The State	Swindles and stock influence	Illegal info transaction			
Market mechanisms	Insider crimes	Price fixing			
	Company plundering				
	Money laundering				

Slide 15: Segment of morphological field for Economic Crime study

We have not yet carried out a morphological analysis concerning Information Technology and its relationship to developing social processes -- which is the subject of this seminar. Such a study would, however, be an enormously interesting undertaking.

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