FOI

Morphological Analysis in Groups: A Personal Guide

MARIA STENSTRÖM

FOI-R--3678--SE
ISSN 1650-1942 Juni 2013

Maria Stenström

Morphological Analysis in Groups: A Personal Guide

Title	Morphological Analysis in Groups: A Personal Guide
Report no.	FOI-R--3678--SE
Month	June
Year	2013
Pages	85 p
ISSN	ISSN 1650-1942
Customer	Swedish Armed Forces
Research Area	6. Metod- och utredningsstöd
Project no.	E113401
Approved by	Göran Kindvall

FOI, Totalförsvarets Forskningsinstitut
Avdelningen för Försvarsanalys

164 90 Stockholm

FOI, Swedish Defence Research Agency
Division of Defence Analysis

SE-164 90 Stockholm

Cover photo: Tomás Saraceno, *32SW/Flying Garden/Air-Port-City/Iridiscent,* 2007. Exhibition at Bonniers Konsthall, Stockholm 2010. Photo: Bonniers Konsthall

Summary

Morphological analysis is a method for formulating, structuring and studying complex problems. This report is a personal guide to morphological analysis as a method for working with groups of experts. I describe what morphological analysis is good for and what morphological analysis is. I give a brief theoretical presentation of the morphological process and the morphological model. Furthermore, I have formulated my own experiences of morphological analysis in practice. It deals with how work groups can be supported through facilitation, how to create good morphological models and model hierarchies as well as what type of aid is required. There are also examples of different types of models and an example that illustrates how morphological analysis can unfold in reality.

Keywords: morphological analysis, morphological model, facilitation, problem structuring, problem formulation, Fritz Zwicky, meta model, scenario, operational analysis.

Preface

What you have in front of you is a guide to *general morphological analysis*. It is based on my own personal experiences of a method that FOI has developed and applied since the beginning of the 1990s. I arrived in 1996 as an apprentice and later became a co-worker of the sage of Swedish morphology, Tom Ritchey. Since then, morphological analysis has been my core competence in working life. I have used the method almost exclusively as a way of helping groups of experts to put their wise heads together in order to achieve common results. More often than not, on behalf of and in dialogue with a paying client. However, it is of course also possible to perform morphological analyses alone in your room[1] or in a research group that is its own client. My guide will also be useful for individual analysis, even if the focus is on group work.

The term morphology means the study of shape or form (from the antique Greek "morphe"). Morphology is about observing and describing patterns within an object, to find out how the parts connect to form a whole. The objects to which we give a form can be physical or mental. Several science disciplines have developed their own morphologies, like zoology, botany, geology and biology (e.g. anatomy). Mental shapes are studied within linguistics (word formation and inflection theory). With general morphological analysis we can study any mental object to create models ("tools for thinking") that helps us to understand complex problems better.[2]

Working with morphological analysis is like riding a bicycle. Once you have learnt, you know how to do it, but describing in words exactly how you do it is impossible. Nevertheless, I shall try and do precisely that, since I want more people to discover and have the desire to learn how to use this method. The guide is my contribution

[1] This is how Iver Johansen at the Norwegian Defence Research Establishment (FFI) has worked, see Johansen, Iver (2006), "Scenarioklasser i Forsvarsstudie 2007 – en morfologisk analyse av

[2] Ritchey, T. (2002), Morphological Analysis – A General Method for Non-Quantified Modelling, FOI, www.foi.se/ma

to the knowledge about morphological analysis. I have chosen to write in a personal way, since morphological analysis is something you grow in to and gradually create your own style.

First I would like to thank my colleagues Anna Lindberg, E Anders Eriksson, Ester Veibäck, Jan Frelin, Maria Bergstrand, Maria Hedvall, Malin Östensson, Per Ånäs and Riitta Räty for their encouragement and intelligent points of view regarding the Swedish texts at various stages and Tom Richey, for a rewarding collaboration during many years. I would also like to thank Iver Johansen, FFI, who reviewed the report. I am most grateful to my project managers Jan Frelin and Camilla Andersson for their support and enthusiasm. Finally, I would like to say a big thank you to everyone who I have had the pleasure of working with in morphological analysis over the years.

Kista June 2013
Maria Stenström

Table of Contents

1 Introduction

1.1 Purpose

The purpose of this report is to increase the knowledge about morphological analysis in practice.

1.2 Quality Assurance

This report is a shortened version of a report in Swedish published in 2012: *Morfologisk analys i grupp: En personlig handledning* (FOI-R--3215—SE). The Swedish version has been reviewed in two seminars at FOI – one informal seminar when the first draft was finished and one formal seminar with an external reviewer, Iver Johansen from our Norwegian sister organisation FFI. Parts of the report have also been reviewed by colleagues at previous stages. The English version has been reviewed by Camilla Andersson and Göran Kindvall.

1.3 The Need for Computer Support

In order to be able to fully apply morphological analysis in groups, computer support is required. We, at FOI, have developed computer software that we use ourselves. Using the computer support tool, we can create interactive laboratories where we can freely select the variables that should be input and those that should be output. This computer software is not for sale. The clients receive a version in the form of a “viewer” where they can look at a finished model, but not change it. It is, however, completely possible to apply morphological analysis with the help of a normal spreadsheet program. I therefore briefly describe how you can do this.

1.4 Reading Guide

I will refer to general morphological analysis as morphological analysis or MA in this report.

In chapter 2, I describe what morphological analysis is good for and what morphological analysis is. I give a brief theoretical presentation of the morphological process and the morphological model. Finally, I sum up my most important arguments for the method. I have chosen to focus this guide entirely on morphological analysis and therefore do not discuss alternative methods. That can wait until another time.

In chapter 3, I have formulated my own experiences of morphological analysis in practice. It deals with how work groups can be supported through facilitation and how to create good morphological models and model hierarchies.

In chapter 4, I illustrate different types of morphological models. I also give an example of how morphological analysis can unfold in reality. I have tried not to style and retrospectively construct too much. It does not matter if you do not understand all the details; I still believe that you can gain an idea about what awaits you as a morphologist.

If you want to read more about morphological analysis, Voros' summary article from 2009[3] is a good place to begin.

[3] Voros, J (2009), "Morphological prospection: profiling the shapes of things to come", Foresight, 11(6): 4-20

2 Morphological Analysis in Theory

2.1 Sonnets and football

When, after a long period of silence due to writer's block, one of Sweden's greatest poets, Lars Forssell, in 1986 published a superb collection of sonnets, he explained that it was the sonnet's strict rules regarding form that helped free up his ability to write and gave him renewed creative power. In one respect, morphological analysis is like writing sonnets (or any other format-bound poem for that matter): it has a strict form and a free content. I have found that this particular relationship often triggers creative power and creative joy within the more prosaic professions that we come across in our work. The strict form also seems to make groups in which there are latent turf wars more interested in "writing a sonnet" than in inner power struggles. Based on my experience, an entirely free form does not have this effect on groups. The group receives a joint project to create a model through morphological analysis from what is quite simply a (un)holy mess.

Another illustration that I usually use when I present the method is the football analogy[4]. In football, there is an established format and established rules. The pitch is such-and-such a size, there are two goals and twenty two players, the aim is to score goals and, preferably, not kick each other's legs too hard. How the teams then play is a question of free creation based on knowledge and skill, current form and inspiration.

2.2 What is morphological analysis good for?

I have sometimes been asked what the disadvantages are of morphological analysis. As far as I am concerned, this question is just as (un)interesting as a question about the disadvantages of a hammer or a screwdriver: "*People who write about methodology often forget that it is a matter of strategy, not of morals. There are neither good nor bad methods but only methods that are more or less effective under particular circumstances in reaching objectives on the way to a distant goal*"[5]. I have a pragmatic view of both methods and tools: If I use a tool (or a method) in the wrong way, then it is not the tool's fault. It is my firm belief that all choices of methods must be based on a solid understanding of the actual method and a thorough diagnosis of the problem in question.

[4] Naturally, any team sport can be used to illustrate this, such as ice hockey or handball.
[5] George C. Homans (1949), from March, James G. (1965), Handbook of organizations, Rand McNally College Publishing Company

The answer to the question about what morphological analysis is good for can be summed up as follows: for taming wicked problems, for creating smart tools for thinking and for refining knowledge. In this section, I expand upon these three areas.

2.2.1 Taming wicked problems

We, as people, strive to find causal relationships. We want to know how A affects B and what it implies. Where possible, we will naturally use cause and effect in order to increase our understanding of the world through causal modelling and mathematical simulation. However, it is not possible to handle many of the problems that we encounter in this way. The uncertainties are too great and their dimensions are essentially different and cannot be quantified or even accurately described.

Nevertheless, we need to be able to explore these "wicked problems"[6], since many of the most significant problems in our world are considered as such. What, then, differentiates wicked problems from other problems? What are their characteristics and how can they be dealt with?

Russell Ackoff has found a good way of illustrating this by dividing problems into three categories[7]:

Puzzle – the simplest form where the problem is well-defined and there is only one right answer. An example of a puzzle is: How much concrete is required to build a certain type of bridge between the island and the mainland? (Another example is a crossword).

Problem – where the problem is well-defined, but there are various answers or solutions depending on what conditions the solution should fulfil economically, technically, ethically etc. An example of a "problem" is: What is the best way of transporting people and goods between the island and the mainland? (The answer can be by bridge, tunnel, ferry, helicopter, rowing boat…)

Wicked problem ("mess") – where the problem is not yet defined. Different stakeholders see different problems (or puzzles) and suggest different solutions. An example of a wicked problem is: Should we, in the municipality, develop the activities on the island and, if so, how?

Here are a few things that characterise wicked problems:

- There are several stakeholders involved
- There are many different perspectives and aspects
- Several specialist areas or disciplines are affected
- Many different dimensions need to be taken into account

[6] More about wicked problems: http://en.wikipedia.org/wiki/Wicked_problem, 18-05-2011
[7] Pidd, M. (1996), Tools for Thinking, Wiley, page 66

- The dimensions are connected in an obscure and partly unknown way
- There are several different possible solutions (to various problems!)
- There is no "right" solution, only solutions that are better or worse
- What is considered a (sufficiently) good solution is simply a matter of opinion
- The resources available determine when it is time to stop looking for the best solution

With the help of morphological analysis, we can avoid what Professor of Management Science, Michael Pidd, conveys so well in the following quote, which is taken from his book Tools for Thinking[8]: *"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."*

The wicked problems can only be solved if we tame them first. Since they are complex and chaotic (non-linear), we must proceed through trial and error in an interplay between problem formulation and problem solving, thus, in cycles of analysis and synthesis. Furthermore, since finding a (sufficiently) good solution is a social process, the stakeholders must be involved in the process. We can do this through morphological analysis.

2.2.2 Creating tools for thinking

The most evident result of morphological analysis is one or several morphological models. In the most extreme case, we have created a ready-made tool that the client uses in its daily operations. I have been involved in two such cases: an instrument that the Swedish municipal fire and rescue services have used to evaluate their preparedness for chemical accidents and an instrument for the importance rating of plants within energy supply. Normally, we develop laboratories to provide support for an in-depth analysis of the problem complex. When the analysis is finished and the conclusions have been drawn, the models are no longer needed and can be filed away.

I believe that morphological analysis successfully fulfils the principles of modelling that Michael Pidd has formulated[9]:

"1. Model simple, think complicated
2. Be parsimonious, start small and add
3. Divide and conquer, avoid mega-models
4. Use metaphors, analogies and similarities

[8] Ibid page 70
[9] Ibid page 115

5. Do not fall in love with data

6. Model building may feel like muddling through"

Morphological models such as tools for thinking can be used for creating and studying:

- Scenarios (frozen moments or time series)
- Strategies and policies
- Road maps
- Operating units (e.g. military units and technical systems)
- Products
- Organisations
- Fault trees, event trees
- Phenomena (energy conversions etc.)

Morphological analysis can also be the first step in building Bayesian networks[10]. I have dealt with this in a case: the risk analysis of unexploded ordnance[11]. The method can also be used as support for creating Analytic Hierarchy Process (AHP) models[12].

Morphological analysis can be used to support games by developing scenarios and system descriptions. The method can also support table-top discussions by creating a structure for reasoning and documentation. I have taken part in this in order to evaluate electromagnetic weapons in various scenarios, among other things.

2.2.3 Refining knowledge

An important result of morphological analysis is that the group coordinates its ideas and opinions and creates a common and distinct language, that is it refines the knowledge that everyone brings with them into the group. Thus, with morphological analysis we can create what David Bohm wanted to achieve with his dialogue method: *"Thus, in a dialogue, each person does not attempt to make common certain ideas or items of information that are already known to him. Rather, it may be said that two people are making something in common, i.e., creating something new together."*[13]

[10] De Waal, A., Ritchey, T. (2007), "Combining morphological analysis and Bayesian networks for strategic decision support", ORiON, 23(2): 105–121, http://www.orssa.org.za

[11] Stenström, M., Westrin, P., Ritchey, T. (2004), "Living with UXO, Using Morphological Analysis for Decision Support in Phasing out Military Firing Ranges. Summary of Report to the Swedish Armed Forces UXO Program", FOI

[12] AHP is a multi-objective method where a hierarchy of criteria is built, against which various alternatives are evaluated.

[13] http://en.wikipedia.org/wiki/Bohm_Dialogue, 18-05-2011, page 1

It is always interesting to see what beneficial effect morphological analysis has on groups. It is as if the simple form of the model and the clear rules enable the members of the group to relax and focus on solving the problem together, instead of trying to take up positions opposing each other. (Naturally, there are exceptions, but they are few).

This means that the dialogue in the group is both open and generous and that everyone learns something new. By everyone contributing to the synthesis, we therefore refine the knowledge that everyone brings with them into the group. There can be a huge amount of structured and refined information documented in a morphological model (provided that one is thorough).

2.3 What is morphological analysis?

There are many answers to the question about what morphological analysis is:

- morphological analysis is a way of creating "gestalts" [14]
- morphological analysis is a base for systematic creative thinking[15]
- morphological analysis is a way of coordinating ideas and opinions
- morphological analysis is a general method for studying relationships between phenomena
- morphological analysis is a way of handling wicked problems[16]
- morphological analysis is a way of creating traceability in assessments
- morphological analysis is cycles of analysis and synthesis
- morphological analysis is a way of structuring and formulating problems
- morphological analysis is a way of systematically investigating all possible solutions to a problem[17]
- morphological analysis is a way of creating scenarios[18]
- morphological analysis is a base for technical design[19]

[14] A "gestalt" is a whole that is greater than the sum of its parts. The Swedish National Encyclopedia Dictionary (Nationalencyklopedins ordbok)

[15] Gerardin, L. (1973), "Morphological Analysis: A Method for Creativity", Bright, J. & Schoeman, M. (eds), A Practical Guide to Technological Forecasting, Prentice Hall, page 445

[16] Can be referred to as "mess" or "wicked problem" in English, see e.g. Conklin, E.J. & Weil, W., Wicked Problems: Naming the Pain in Organizations, www.leanconstruction.dk/_root/media/15.pdf 18-05-2011

[17] Gerardin, L. (1973), "Morphological Analysis: A Method for Creativity", Bright, J. & Schoeman, M. (eds), A Practical Guide to Technological Forecasting, Prentice Hall, page 445

[18] Coyle, R. G. & Yong, Y. C. (1996), "A Scenario Projection for the South China Sea", Futures, 28(3): 269-283 and Rhyne, R. (1995), "Field Anomaly Relaxation, The Arts of Usage", Futures, 27(6): 657-674

[19] Norris, K. W. (1962), "The Morphological Approach to Engineering Design", Jones, J. C. & Thornley, D. G. (eds), Conference on Design Methods, London: page 115-140

It was the world-famous astronomer Fritz Zwicky who, in the 1940s, coined the concept of General Morphological Analysis and developed it as a method. He used morphological analysis to study everything from galaxies and stars to the legal aspects of space travel and colonisation. Tom Ritchey has summarised Zwicky's contribution to morphological analysis in an article that I can warmly recommend.[20]

FOI took up morphological analysis at the beginning of the 1990s when Tom Ritchey began developing an enhanced "typology generator"[21] in order to create scenarios in a systematic and traceable way. At the same time, he looked for similar existing methods and that is when he found Fritz Zwicky's morphological analysis. Since then, we at FOI have developed the method further and applied it to a hundred or so different problems. FOI has also developed a computer support tool, Casper (Computer Aided Scenario and Problem Evaluation Routine), which is an essential element in order to be able to fully use the method in groups. However, it is totally possible to work with a spreadsheet program, especially if you are doing the work alone or in a work group that has plenty of time.

Fritz Zwicky described morphological analysis as follows (figure 1):

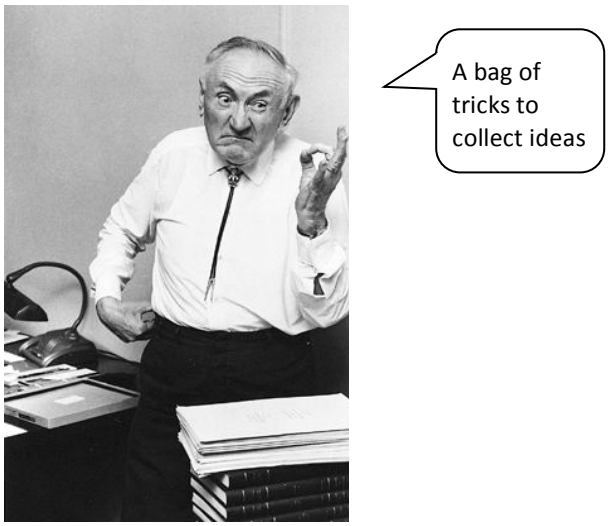


Figure 1: Fritz Zwicky. Photo: Floyd Clark 1971

[20] Ritchey, T. (2006), "Problem structuring using computer aided morphological analysis", Journal of Operational Research Society, 57(7): 792-801

[21] The simplest form of typology is the four-field diagram, a very simple model with two dimensions from which four types can be generated. A classic example is the blood types A, B, AB and 0, which can be described using the dimensions Base substance A (exists-does not exist) and Base substance B (exists-does not exist).

This is my interpretation of this somewhat cryptic quote:

Trick no. 1: The morphological model
In morphological analysis, we work with a simple visual form that provides an overview and shows details. It gives the problem a visible gestalt that we can study and refine. A description of the morphological model can be found later on in this chapter.

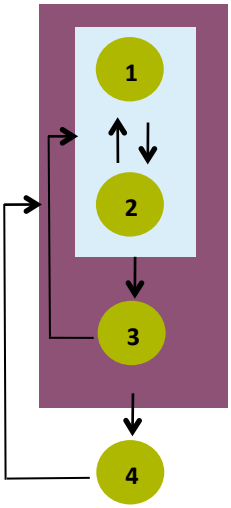
Trick no. 2: Breach limits in a structured manner
In morphological analysis, we encourage free thinking within the framework of an established form. It helps us to consider what is politically, economically, technically, ethically, culturally or organisationally impossible today, but that can become generally accepted faster than we think.

Trick no. 3: Study connections, but ignore cause and effect
In morphological analysis, we study the connections between all the dimensions of the gestalt. We study all possible combinations without trying to find out what the cause is and what the effect is. In this way, we can find new, unexpected solutions.

2.4 The iterative MA process

Morphological analysis involves performing cycles of analysis and synthesis in a traceable and transparent way. In other words, it is nothing more than a good old-fashioned scientific method! If you wish to read something worthwhile about this, then you should read Tom Ritchey's excellent paper on analysis and synthesis.[22]

What we do with morphological analysis is break the problem down into its component parts, examine these parts, select a few of them and then put them together to create a meaningful whole (figure 2). We always start with the whole, get down to the "nuts and bolts", and finish with the whole. By doing this several times, we learn more about the problem, see it from different angles and can find (sufficiently) good solutions.



1. Identify and describe dimensions (analysis)
2. Identify and describe conditions (analysis)
3. Create configurations (synthesis)
4. Assess the configurations (synthesis)

Figure 2: Morphological analysis is cycles of analysis and synthesis. The terms are described in the next section, which deals with the morphological model.

By completing several cycles, we can create meaningful and clear dimensions and conditions and dive really deep into the wicked problem in order to finally arrive at a well thought-out problem formulation and a number of alternative solutions. For each cycle completed, we increase the quality of the content. This means that morphological analysis has a built-in quality assurance function.

[22] Ritchey, T. (1991), "Analysis and synthesis. On Scientific Method - Based on a Study by Bernhard Riemann", Systems Research, 8(4): 21-41, www.foi.se/ma.

2.5 The morphological model

Now, it is about time that I present the morphological model. A morphological model is a way of describing in concepts and words how different dimensions in a complex problem are connected.

I think that it is easiest for me to first describe the morphological model with the help of a concrete example, and then go into the details. Figure 3 describes a morphological model and the terminology that I usually use. The example is taken from a morphological analysis we made a few years ago when we were commissioned by a public housing company. The management there wanted to use the morphological model in a dialogue about the future with the politically appointed board.

We worked directly with the management team, within which there were various competencies, such as finance, property management and market relations. We started by discussing what it was that affected the housing company and how the company would describe its activities, for example the housing market in the region, the development of the rents and the maintenance of the housing stock. I usually call these *dimensions*, but they can also be called factors, variables, parameters or perspectives.

Once we had agreed on a number of dimensions, we deliberated over their nature and whether they could be expected to develop in various ways over the coming ten years: we illustrated the development of the housing rents with five different increases in per cent per year, and new production with the number of newly-built apartments per year. I usually call these different developments *conditions*, but they can also be called values or states.

The next step was to examine how the different dimensions were connected. We did this by combining, pairwise, all conditions with each other and determining whether or not they could coexist. (Not everything in this world goes with everything: if I choose A, I may not be able to get B at the same time). In this way, we created a coherent picture showing what was possible and what was not possible. The result was several combinations of conditions that I call *configurations* or *scenarios*. With the help of these, we could clearly see what strategy (i.e. on what level the company could pursue its activities) should be implemented when different external conditions apply. I can say that the dialogue with the board was both interesting and informative. All of the politicians stayed for the entire day, showing that they were impressed with the method.

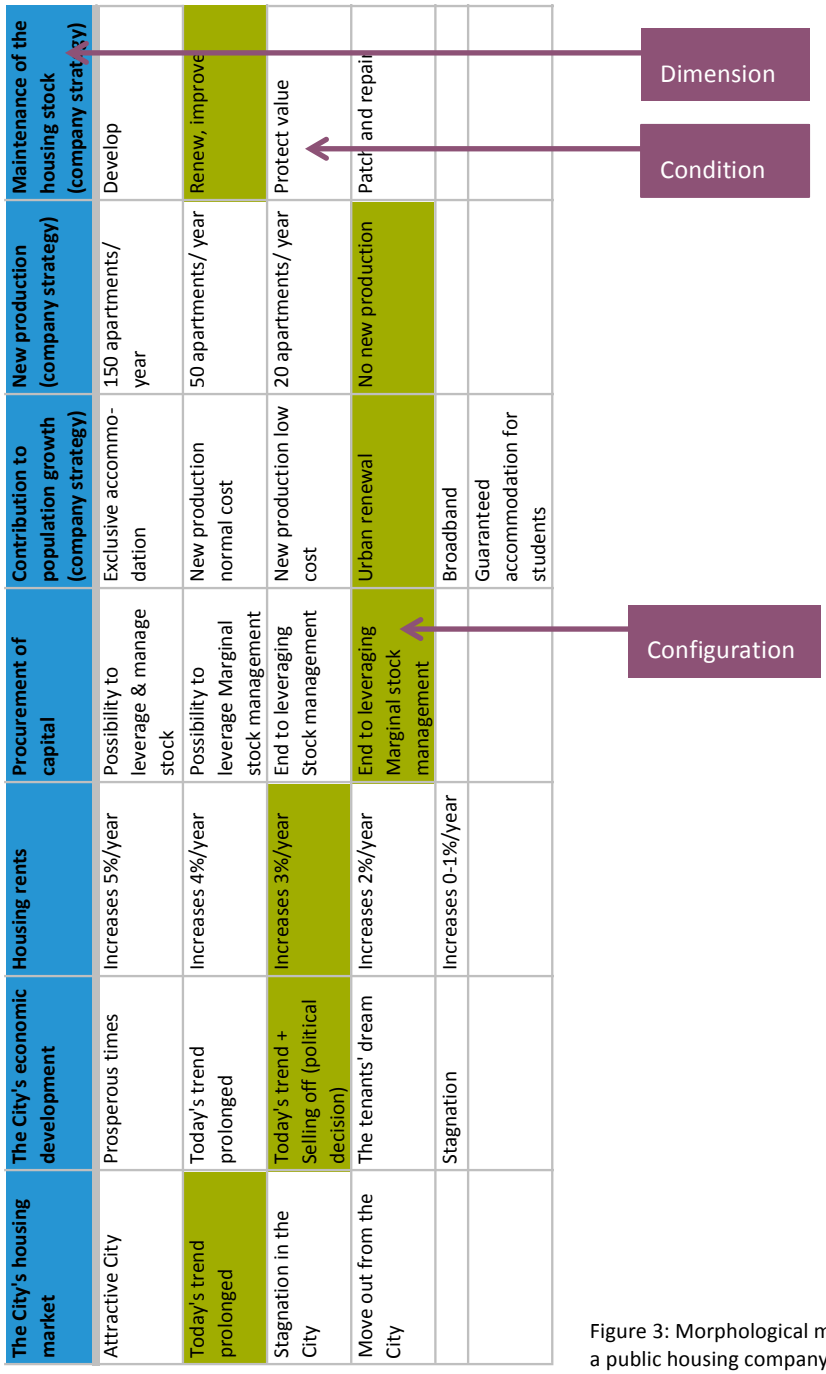


Figure 3: Morphological model for a public housing company.

A morphological *model* can also be called a morphological field, matrix or "morphological box"[23]. (One piece of advice is to adapt the terminology to the group you are working with).

2.6 Dimensions

The dimensions in a morphological model are variable concepts, such as population growth, price of energy, interest, terrain, climatic zone, type of sensor or response time. They are the most important components of the problem complex and together constitute its *gestalt*. A dimension is not the same as a fixed condition, since a dimension always has at least two conditions.

Dimensions can be widely different phenomena since it is possible to create models of everything imaginable with morphological analysis. Creating a model always helps to simplify the problem (and that is also quite simply the point!). With the help of morphological analysis, we can create traceability, meaning that we can clearly see what dimensions we have chosen and those we have dismissed (also document them and justify why).

2.6.1 Number

The point of morphological analysis is to study several dimensions at the same time and, with their help, to create meaningful gestalts. In order to make this possible, we need to stay within the bounds of human ability when it comes to simultaneity. Since the limit for what most of us can keep in our heads at the same time is seven different things, plus or minus two[24,25], an ideal morphological model consists of maximum seven or eight dimensions. However, larger models can be built if you are a bit smart. You can read more about this in chapter 3.

2.6.2 Qualities of a good dimension

Since morphological analysis is based on judgement, filtering out good dimensions is more of an art than a technique. Experience has shown that a good dimension has a few specific qualities, besides of having at least two conditions:

- It is meaningful to those who build the model
- It is just as important as all the other dimensions
- It has the right level of abstraction/level of detail

[23] Fritz Zwicky's terminology.
[24] Miller, G. A. (1956), "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information", Psychological Review, 63: 81-97
[25] Baddeley, A. (1994), "The Magical Number Seven: Still Magic After all these Years?", Psychological Review, 101(2): 353-356

- It is straightforward
- It is independent
- It has (many) connections to other variables

Meaningful to those who build the model
We always work with a work group where the members can provide different perspectives to the problem complex. It is the experts in the work group who decide which dimensions are meaningful to them. More about this in chapter 3.

Just as important as all the other dimensions
A basic rule is that all the dimensions in the model must be about as important as each other.[26] This is because we must simplify a complex reality and can therefore only include important dimensions in the models. This requires that we dive deep into the wicked problem and complete at least two cycles of analysis and synthesis.

Right level of abstraction/level of detail
There is no answer to what is the "right" level of description. A rule of thumb is that all dimensions should be described at the same level of abstraction/level of detail, so that they are comparable. Since morphological analysis is an iterative process in which you go from high to low and back again several times, the group gradually approaches the right level.

Straightforward
A dimension should, in theory, be so straightforward that it cannot be misinterpreted. This is not always possible to achieve in practice, but we should always strive for this. Since we are working with words, it is important to choose the names of the dimensions with great care. Sometimes, it is necessary to change the name of a dimension several times in order to make it as clear as possible.

Independent
Ideally, all dimensions should be completely independent, but morphological models work even if the dimensions slightly overlap each other (known as "fuzziness"). However, strive to keep them independent where possible.

Connection with other dimensions
A good dimension has interesting connections with at least one other dimension in a morphological model. You can read about how to find out about this in chapter 3.

2.7 Conditions

The conditions that together make up a dimension in a morphological model can form scales or be separate points in no particular order.

[26] Gerardin, L. (1973), "Morphological Analysis: A Method for Creativity", Bright, J. & Schoeman, M. (eds), A Practical Guide to Technological Forecasting, Prentice Hall, page 448

Scales consist of conditions that have a particular order of priority and are mutually exclusive. The simplest form is of the “high-middle-low” type, but it is most often possible to attach more interesting words to the conditions. The dimensions in figure 3 are all expressed as scales.

A special kind of condition is what we usually refer to as the “off switch” (or NA – not applicable). It is a condition we use to create configurations in which certain dimensions should not be included.

2.7.1 Number

Normally, we give a dimension between three and six/seven conditions. Two is the minimum (otherwise it is a fixed condition and not a dimension). The visual impression and our ability to create gestalts are what actually limits the number of conditions. Up to fifteen conditions in a dimension can work, but this is about the practical limit. You miss the point of morphological analysis if you have several dimensions with many conditions in that it becomes difficult to create gestalts in the model.

2.7.2 What is a good condition?

Just as dimensions should be straightforward, so should their conditions where possible. However, then they can actually take on any form. The most important thing is that they cover all the possible values of the dimension. A rule of thumb is that there should be distinct differences between the conditions, regardless of whether they are in a scale or in separate points in no particular order.

2.7.3 Different types of conditions

There are two types of conditions:

- Simple conditions
- Complex conditions
  - Four-field diagrams
  - Chinese boxes

Simple conditions are concepts that describe a single phenomenon, such as precipitation in the form of hail, snow or rain.

Complex conditions are what we create when we combine two or more phenomena. This is both a way of saving on dimensions and a way of avoiding multilateral comparisons (see below). The simplest thing is to combine two phenomena in a four-field diagram. If we wish to combine several phenomena, we build a separate

morphological model that I usually call a "Chinese box".[27] Here, we create complex conditions in the form of whole configurations. You can see what this looks like in the Future Agriculture example in chapter 4.2.

2.8 Configuration

A configuration is a combination of at least one condition from every dimension (figure 4). It can be a scenario, a strategy, an organisation or any other complex phenomenon. You can find several examples in chapter 4.

Dimension A	Dimension B	Dimension C	Dimension D	Dimension E
a1	b1	c1	d1	e1
a2	b2	c2	d2	e2
a3	b3	c3	d3	e3
a4		c4		
		c5		

Figure 4: A configuration must contain at least one condition for each dimension in the morphological model.

The conditions of each configuration should be internally consistent. To ensure this it is necessary to evaluate all pairs of conditions, to identify possible and impossible combinations. Figure 5 shows what the pairwise comparison looks like in the form of a so-called cross-consistency-matrix, where all the conditions in two dimensions have been compared to each other.

	Dimension A			
Dimension B	Condition a1	Condition a2	Condition a3	Condition a4
Condition b1	Yes	Yes	No	Yes
Condition b2	Perhaps	No	Yes	No
Condition b3	Yes	Yes	No	Yes

Figure 5: Pairwise comparison of the conditions in dimensions A and B illustrated in a cross-consistency-matrix[28].

There are two ways of carrying out pairwise comparisons: empirically and normatively. In the first case, we answer the question: *can* these two conditions coexist (logically and empirically) given the conditions that we have chosen for the model

[27] A Chinese box is a smaller box inside a bigger box that is in an even bigger box, thus the same thing as a Russian doll.

[28] Can also be called "compatibility grid", see Friend, J. (2009), "The strategic choice approach", Rosenhead, J. and Mingers, J. (eds), Rational Analysis for a Problematic World Revisited, 2nd ed., John Wiley&Sons

(e.g. time perspective and scope). In the second case, we answer the question: *may* these two conditions coexist given the conditions that we have chosen for the model? We can add restrictions here, such as ethical, legal or economic restrictions.

How to work with configurations in practice is described in chapter 4.8.

2.9 My most important arguments for morphological analysis

1. We can **tame wicked problems**, requiring us to work in cycles of analysis and synthesis. Morphological analysis helps us to perform both analysis and synthesis in groups of experts and stakeholders, in a traceable and transparent way. This means that we can shine a light on the problem from several perspectives and, together, try out different solutions.
2. We can **create smart tools for thinking.** Sometimes, we need to think both broadly and deeply in order to solve problems. With morphological analysis, we create a gestalt, a general picture of a problem complex, where we can systematically study all the connections between the dimensions. We can dive deep into the problem without losing sight of the whole, increase our knowledge and, in the best case, discover new, unexpected solutions.
3. We can **refine knowledge in an effective way**. Several heads are better than one – if the conditions are right. The established and simple form and the clear rules mean that the group can focus entirely on the content and not on the forms of cooperation. Thus, morphological analysis promotes constructive dialogue between representatives for different matters and interests and makes us aware of the importance of clarifying the concepts we use. This results in us creating a common language in order to describe the problem.

3 Morphological Analysis in Practice

3.1 A few introductory words

As a morphologist, you need to understand the morphological model in theory, as well as know how you should carry out a morphological process in practice. In this part, I describe the MA process chronologically, from diagnosis, through the building of models in a work group, to documentation of the process and its results.

3.2 Diagnosis

The aim of the diagnosis is to create an initial picture of the wicked problem and ascertain what the client wants to achieve from the morphological analysis. The client can be anything from a paying customer (like in my world) to a research group with fixed funding that wants to carry out a morphological analysis internally (and therefore is its own client). It takes approximately two hours in a group of experts. If you are to carry out the morphological analysis alone in your room, then you will possibly conduct the diagnosis single-handedly. The visible result is a sketch of one or several morphological models and an idea for a focus issue (see 3.6).

The group must consist of people with different perspectives of (what we believe is) the problem. An adequate group size is three to five people, but there may be situations where it is more appropriate to have more or less people.

Here are some suggestions on the content of the diagnosis:

- Short MA presentation
- Sketch out an external environment/internal environment model[29] on the board
- Ask everyone around the table: How do you want to formulate the problem?
- Start to sketch out one or several models (on the whiteboard). Ask:
  - What are the most important dimensions for describing the problem?
  - What conditions can they have?
  - How much detail do you want to include?
- Sketch out an initial meta model, i.e. how the models are connected if there may be several models

Carefully document all that is said during the diagnosis. That information will be absolutely necessary as the work progresses.

[29] See 3.9.

3.3 Preparations

Before gathering the work group together, there are a few things you need to do first. You need (together with the client, if there is one) to select the participants of the work group. You also need to decide when, how often, where and for how long the group should work on the morphological analysis. You also need to come up with a suggestion for a focus issue for the first workshop.

3.4 The work group

The work group is both the starting point for and the most important guarantee of quality in a morphological analysis[30]. You must therefore be very careful when selecting group participants. (Select participants in consultation with the client, if there is one).

In addition to experts, there is also the need for facilitators, who support the group. It is best if there are two facilitators, then they can take turns to facilitate the work ("be on the floor") and to document and reflect on what the group says. You can read more about facilitation under the section Facilitation of morphological analysis.

A work group should ideally consist of four to seven people, since we want to initiate a dialogue between the participants. There must be a critical mass. In extreme cases, three people may be sufficient for that. The group must not be too big. A group of eight or nine people may work if they already know each other. If the group is too big, one of the following things happens:

- the group breaks up into several smaller groups, e.g. for their own discussions
- all communication goes through the facilitator
- a few people talk to the rest of the group

If you want more people to be involved, then there are two ways of solving this. You can create a reference group that is allowed to provide its views on the models on one or several occasions during the course of the process. This group can be big. You can also create two or more sub-groups that deal with different parts of the problem complex. This requires the first structure to be in place so that you know what models should be developed.

The analysis requires continuity, but it is actually a good idea to take in new participants, either permanently or temporarily (in order to highlight a certain issue).

[30] It is possible to perform morphological analysis alone in your room. This is how Fritz Zwicky worked. However, at FOI, the method has always been a way of working with groups of experts.

What is essential is that there is a core group of three to four people who are involved from beginning to end.

3.5 When, how often, where, for how long

Choose a time when you can run workshops, with a maximum interval of one month and a minimum interval of four working days. It is ideal to have a gap of one to two weeks between each time. In that way, the participants have time to reflect and fill in any gaps in knowledge, and you have time to adjust the structure and propose well thought-out suggestions for the continuation of the work. If too much time passes between each workshop, the take-off takes too long, and you lose tempo.

An MA workshop can be between half a day and two days long. If the participants of the group need to travel, it is more practical to have two days in a row. If the participants are very busy, it may not be possible to have more than half a day at a time. You must quite simply adapt to the circumstances.

3.6 Focus issue

Morphological analysis can be applied to all kinds of matters. There is therefore no checklist or established logic to rely on when the process starts. We always start with an empty form. In order for the process to start, the participants of the work group must first agree to a reasonable extent among themselves on what we are doing. We do this by formulating together what is known as a focus issue. This acts as a compass when the process feels messy and there are many suggestions up in the air. The focus issue is particularly important at the beginning of the MA process; it is like a succinct summary of a large piece of material. We often reformulate the focus issue as the problem starts to be resolved (see the example below).

Example of focus issue: Evaluation Instrument for Chemical Accidents

The Swedish Rescue Services Agency commissioned us to develop a simple computer-based instrument that would help the municipal fire and rescue services to evaluate their ability to handle accidents involving hazardous chemical substances.

The focus issue we started with was: "*We will model the fire and rescue services' resources and ability to act with regard to a certain type of chemical accident*".

This issue gave rise to quite a long discussion about what the evaluation instrument should show. The initial reaction was to evaluate the actual (practical) ability. We began creating a few morphological models in order to unravel the mess.

We then found that the actual ability cannot be properly evaluated beforehand, since it greatly depends on the special circumstances in each individual case. For example: Who is on duty? Is all the equipment fully operational? Has the accident happened in a particularly inconvenient place? What chemical substance is involved?

We now realised that the instrument should provide overall knowledge about the general ability.

We therefore reformulated the first hypothesis to: "*We will model the fire and rescue services' preparedness for a certain type of chemical accident and not the actual ability in a real situation*".

This may be seen as a small difference, but it was vital to the entire analysis. Without it, we would not have been able to create a simple instrument, but rather ended up with a complicated simulation model with many variables in a "black box".

3.7 Facilitation of morphological analysis

In this section, I describe how you can work in order to facilitate matters for the group, for example by using Socratic questioning and meta models. I also write about the rules that we have formulated for morphological analysis and how you can work in groups in order to build and study the morphological models.

3.7.1 Facilitation and morphological analysis

Fritz Zwicky used morphological analysis alone in his room as a way of studying phenomena in space, energy conversions etc. And that is of course a good way of

using the method. But we at FOI have always considered morphological analysis as an excellent method for bringing cross-disciplinary and cross-sectoral groups together for *co-creation*. We realised very soon that morphological analysis in groups requires *facilitation*. What you as a facilitator must do is support the work group through cycles of analysis and synthesis as best as possible.

3.7.2 What is facilitation?

Facilitation[31] is the act of supporting a group in its knowledge process. It is the group that achieves the result with the help of the facilitator.

I usually compare the work of the facilitator to that of the midwife. The midwife facilitates the birth based on her know-how and experience, but it is the mother who gives birth to the child (hopefully with the kind help of her partner). Facilitation is all about listening, reformulating, asking questions, sorting out, summarising and making suggestions.

Your task as a facilitator is to have an overview and see patterns in the discussions, to maintain a good atmosphere in the group and to help the group forward in a responsive, yet clear way. You make sure that the group keeps to the subject and that everyone in the group has their say and actively participates. You simplify the discussion when it becomes too messy and get it going when it comes to a standstill. As a facilitator, you always remain neutral.

I do not consider facilitation to be the same as process management or steering. Perhaps slightly exaggerated, but it could be said that in process management the group is more of a *source* from which the process manager draws knowledge in order to be able to solve a problem back office. In facilitation, the group is always the key player and the one that, with the *help of* the facilitator and a minimum amount of back office support, solves the problem.

3.7.3 Socratic questioning

Socratic questioning is the most important technique when I facilitate morphological analysis. The point of Socratic questioning is to help people to formulate what they know and are capable of. The Ancient Greeks were already aware of the method. Plato described how his teacher, Socrates, used investigative questioning in his teaching[32]. You listen, formulate new questions, summarise and make

[31] Christine Hogan has written several books on facilitation, including Hogan, C. (2003) "Understanding Facilitation: Theory and principles", Kogan Page

[32] The fact that Socrates was sentenced to death for having led the young people on shows that the method was considered to be powerful even back then. In our enlightened times, we have realised the benefits of Socratic questioning, which is used today in cognitive behavioural therapy, for example.

suggestions based on the needs of the group or the individual. Socratic questions have no right or wrong answers. They are investigative and encourage individual and creative thinking. Examples of Socratic questions are:

- Can you expand upon what you mean?
- Can you give an example?
- Can this be done in any other way?
- How does it work?
- Can you imagine the opposite?
- How were you thinking now?
- Could this be done as well/instead?

3.7.4 Rules for morphological analysis

We at FOI have formulated a number of rules for morphological analysis, a kind of credo for our way of working with morphological analysis in groups. The rules are well-tested and they work. Present the rules during the first workshop, and remind people about them if necessary.

- Everyone in the work group is equally important, regardless of the position they hold in their own organisation
- Everyone in the work group has insight into what takes place during the course of the work
- We do not accept hidden agendas
- We do not use voting
- Minority rights apply, everyone's ideas are put up for discussion
- We test all ideas before possibly rejecting them
- Disagreement on details is OK, it can be dealt with
- We encourage jokes and laughter. It promotes creativity

3.7.1 Venue and technique

The venue should be furnished with U-shaped seating or with a wide rectangular table so that the participants have just the right amount of contact with each other. I think that it is a good idea to have tables as the participants often want to be able to take notes. Some people also feel uncomfortable without the protection a table provides. However, feel free to try working without tables if you prefer. The venue must not be too small and it should have good ventilation.

A large part of the work is creative and experimentation, especially during the introductory phase. There must therefore be at least one board to write on, preferably more. Flip charts are also good to have. I always work with a computer and a video projector after the introductory phase, since it is practical when it comes to documenting so that it is visible to everyone. If you do not have customised software, use a spreadsheet program.

One question I am quite often asked is whether I use “post-it”-notes. I do not use them, but there is nothing to prevent you from using this technique to put forward suggestions for dimensions if you feel comfortable with it.

3.7.2 A mixed bag of advice

Alternate
Facilitating morphological analysis is often like “herding cats” – your mind must be completely on the job and you must always be at the top of your game. It is ideal to work as a pair of facilitators, especially at the beginning of an MA process. This allows us to alternate, which is good for both the group and the facilitation. When one is working on the floor, the other can reflect on what has been said, pick up ideas that can drive the process forward and, at the same time, be in charge of the documentation.

Maintain openness
Do not be afraid of disagreement in the group, it is a sign that the participants are laying all their cards on the table. However, make sure that nobody silences dissenting voices by virtue of their position in the hierarchy. The “dissidents” may be those that express possibilities yet to be explored.

Confusion is a good sign
Do not worry if the participants seem sceptical or unconvinced at the end of a workshop day. The more confused they are after a workshop, the more you have achieved. The process report will give them a solid ground to stand on prior to the next meeting.

Post-morphological depression
Conducting a morphological workshop involves a substantial intellectual and emotional discharge. We work intensively with a problem that is both “wicked” and offers resistance. The problem eludes us and slips away, making us sometimes believe that we have lost a hold on it. This can give rise to what I, in the spirit of Freud, call “post-morphological depression”. This normally happens at the end of a workshop day. The group is simply deflated. But do not despair. It is completely normal and it will pass. I usually inform the group about this when we start our journey together so that no one is surprised and becomes deeply disappointed.

Keep the vision alive!
If the wicked problem is extremely complicated, you, as a facilitator, need to keep the vision alive, since it is easy to start feeling despondent. In my experience, the group is often very close to a solution when the level of doubt is at its greatest. Unfortunately, you cannot see this until afterwards, but, as an experienced morphologist, I *know* that everything will turn out well, even when things seem at their darkest. Trust your intuition and gut feeling that you see “something”, even if you cannot yet put it into words in a clear and concise way.

3.8 Work with the morphological model

We are now going to approach the group work with regard to developing and studying the morphological model. Morphological analysis is simply cycles of analysis and synthesis and we run through the following steps in a cyclical process (see also chapter 2: The iterative MA process):

- Identify dimensions and conditions (analysis)
- Create configurations (synthesis)
- Examine the model and the configurations (synthesis)

It is advisable to use a standard spreadsheet program to visualise the model, if one has not customised MA software available.

3.8.1 Identify dimensions and conditions (analysis)

The first step in a morphological analysis is *analysis* of the wicked problem. We start with the situation as it is expressed in the focus issue. Using it as a compass, we start looking for the most important dimensions and their conditions. The group decides what is most important. It can be a little tentative at the beginning, but the more the participants learn about the problem, the more confident they become in their assessments.

Dimensions
There are various ways of identifying dimensions.[33] You can put the question directly to the group, and then you often get a number of different suggestions. If things are slow, I like to use Kipling's *"six honest serving-men (They taught me all I knew); Their names are What and Why and When and How and Where and Who".*[34] Other techniques that can be used during this first phase are, for example, brainstorming with post-its, mind maps or allowing the participants to write scenarios before the first work meeting.[35]

Regardless of what you do, the result should be a gross list of possible dimensions. The group must now agree upon the six or seven most important ones to start modelling. I strongly advise against voting as it disrupts the dialogue within the group (and goes against the MA rules). Allow it to take time instead. Do not take the first choices so very seriously and try to start building the model. And remember that the first set of dimensions and conditions will change. Proceed through trial and error. The good dimensions and conditions will gradually take shape. The more experience you gain, the easier you will find it to see what dimensions will

[33] See Chapter 2
[34] From Kipling's tale The Elephant's Child
[35] Coyle, R.G., Young, Y.C. (1996), "A scenario projection for the South China Sea", Futures 28(3):271

work. Document leftover dimensions so that you can bring them up later in the process. They are also important for traceability, in order to show what we dismissed.

A pedagogical trick is to sort the dimensions into some kind of logical order when they start to materialise.

Conditions

The way of identifying the conditions of dimensions does not differ in principle from the way of identifying dimensions. However, there are a few technicalities that can be good to learn.

The aspects that I wish to emphasise are order of priority and relationships between conditions within a dimension and type of condition.

Order of priority implies that the conditions form a scale. It has its advantages, such as being able to explore limit values. However, it is not always possible to create a scale. In those cases, we have to work with points in no particular order. It is not always obvious from the beginning if it should be a scale or separate points, so be open to what the group says and ask Socratic questions such as whether or not the group believes that the dimension's conditions are a scale.

If the feeling is that it could be a scale, you should always start with the *limit values* and then add the appropriate amount of conditions between them. Keep in mind that morphological analysis is not about the details, but rather about the essence. Working with limit values is good since they open the way for creativity – you are allowed to reach a little bit further than that which common sense permits. Ask Socratic questions such as: What is the most extreme thing you can imagine? [36] What does your dream solution look like?

One question that should be answered is how to prioritise from a purely graphical point of view. Should that which the group sees as “best” or “highest” appear at the top or at the bottom?

You can start with limit values even if it ends up in points. If it concerns points, work as with dimensions.

The next aspect deals with the *relationships* between the conditions within a dimension. They can be mutually exclusive, so that only one condition from each

[36] A clear example comes from a study Tom Ritchey conducted in 1995 about the future of the bomb shelter programme. The question was “what do we do with bomb shelters now that the Cold War is over?” One of the dimensions was “geographical priority”. The conditions constitute a scale with the limit values “Only big cities” (i.e. Stockholm, Gothenburg and Malmö) and No geographical priority. Everyone knows that the latter is impossible, but it must be included as a reference point. The former was almost not allowed to be said out loud when we did the study. However, it was fully accepted as a priority only a few years later. Later on, it was taken even further.

dimension exists in the same configuration. This is what we usually call “or-conditions”.

Fritz Zwicky believed that the conditions in a morphological model should be mutually exclusive. The model in figure 6, energy conversions, is an example that he himself used to present morphological analysis:[37]

Initial energy form	Transmission form	Final storage form
K (Kinetic)	K (Kinetic)	K (Kinetic)
E (Electrical)	E (Electrical)	E (Electrical)
C (Chemical)	C (Chemical)	C (Chemical)
T (Thermal)	T (Thermal)	T (Thermal)
N (Nuclear)	N (Nuclear)	N (Nuclear)

Figure 6: Zwicky’s morpholocial box for energy conversions

We at FOI have deviated from classic morphological analysis on this point. We also create dimensions with conditions that can be found at the same time in one and the same configuration. We call them “and-conditions”.

We sometimes try to avoid and-conditions in order to make the models easier to review. You solve this through forming scales by adding conditions to each other in “packages”. First, define a basic package and then gradually add conditions one step at a time until you reach a maximum level. Example: In the “Amphibious Battalion” study, we created packages that describe coordination possibilities. We ended up with the following conditions for the dimension Coordination:

- only within the Amphibious Battalion (basic package)
- within the Royal Swedish Navy, including the Amphibious Battalion
- within the Swedish Armed Forces, including the Royal Swedish Navy
- within the Swedish Total Defence Service, including the Swedish Armed Forces
- international coordination, including the Swedish Total Defence Service

The third aspect deals with how to design your conditions, whether they should be simple or complex. You can read more about this in chapter 2. In practice, you have to quite simply proceed through trial and error and trust your own judgement and that of the group.

Personal process tips

I want to quickly arrive at a first model to evaluate and examine in order to then modify dimensions and conditions. I use the whiteboard and the focus issue to get started. I ask the question: “What are the most important dimensions for describing this problem?” All the participants are then allowed to make suggestions, which

[37] Ritchey, T. (1998) “Fritz Zwicky, Morphologie” and Policy Analysis, 16th Conference on Operational Analysis, Brussels

I write up on the board as they are put forward. I usually also ask for conditions as the dimensions are being suggested, in order to make them clearer.

I am careful when it comes to checking that everyone in the work group understands the dimensions and their conditions, but I do not strive for exact definitions since this stifles the MA process. Try to capture the essence instead. The Canadian Philosopher of Science, Ian Hacking, phrases it like this: *"Don't first define, ask for the point"*.[38]

It happens quite often at the beginning of a morphological analysis that the model rapidly grows in all directions. Then, you need to take a break. Look at the model and contemplate whether or not you should divide it up and, if so, how. Consult each other if you are two facilitators (which I recommend!). When the group comes back, you make a suggestion as to how you should proceed. It is generally advised to make use of breaks for back office work during the meetings. Thus, as a facilitator, you do not get many quiet moments when working with the group, so it is important to rest afterwards.

During the pioneering days, we were quite orthodox when it came to the fact that the group should be involved from the very beginning when we created the models. Now, I can see the point of sometimes creating a "semi-finished product" alone in my room or with some colleagues prior to the first workshop. Bringing along a first suggestion for a model speeds up the process, which is important when there is very little time in the group. In this case, however, it is of course all the more important to have input from the client and to have done a thorough diagnosis.

3.8.2 Create configurations (synthesis)

It is appropriate to first decide (approximately) how many configurations you want. The configurations should be interesting, preferably ambitious, and different to one another. You need to do this in an iterative process, so that the set as a whole is balanced.

Here, I will describe how you can create configurations with the support of a spreadsheet program. It is done in two steps.

Step 1: Evaluate internal consistency
Since all conditions in a configuration should be consistent it is wise to first evaluate all pairs of conditions in the morphological model, to sort out impossible combinations. (A quick fix if time is short is to simply check that all chosen conditions in each configuration go together.) We do this with the help of a cross-consistency matrix (Figure 7).

[38] Hacking, I. (1999), "The Social Construction of What", page 5, http://www.amazon.com/Social-Construction-What-Ian-Hacking/dp/0674004124#reader_0674004124 18-05-2011

		Dimension A				Dimension B			Dimension C					Dimension D		
		a1	a2	a3	a4	b1	b2	b3	c1	c2	c3	c4	c5	d1	d2	d3
Dimension B	b1	No	Yes	?	Yes											
	b2	Yes	No	Yes	?											
	b3	Yes	Yes	No	Yes											
Dimension C	c1															
	c2															
	c3															
	c4															
	c5															
Dimension D	d1															
	d2															
	d3															

Figure 7: Cross-consistency matrix. All conditions of all dimensions are compared to each other in pairs to judge whether they go together or not.

Facilitating the pairwise comparison of consistency is actually quite easy. It is simply a case of working one's way through all pairs of conditions. Just remember that it does not concern causal relationships. I usually work with a general comparison question: Can (or may) these two conditions coexist given the general conditions for the analysis? Of course it is possible to develop more detailed and specific comparison questions if you feel more comfortable with that.

The answers to the comparison question I use are:

- Yes, with no reservations (red in figure 7)
- No, without doubt (green in figure 7)
- Maybe, if some specified conditions are at hand (grey in figure 7)

Sometimes it is not possible to make a judgement of reasonable quality during a workshop. In such cases put a question mark for that pair in the cross-consistency matrix and consider it again when more knowledge is at hand. Document why there is a question mark and ideas about what could be done to straighten it out.

I usually use the following procedure:

1. Briefly judge whether the two dimensions in question have conditions that do not go together
2. Compare the conditions of the first dimension to those of the second dimension, third dimension etc.
3. Compare the conditions of the second dimension to those of the third dimension, fourth dimension etc.

If the conditions are scales, a trick is to start by comparing the extremes to each other (four combinations).

Take advantage of the opportunities to refine dimensions and conditions in the pairwise comparison. If they are poorly or vaguely formulated, then it will be difficult to make comparisons. Then, go back and improve the model and make it clearer.

If the group finds that it lacks know-how when it comes to comparing certain pairs of conditions, assign homework or make sure that the right competence is included in the group during the next work meeting.

Remember to document all justifications, and other comments, for the comparisons! Here, you build a relational database with a lot of valuable information – one of the results of morphological analysis. This is particularly important if there are ambiguities (often due to the fact that the group lacks know-how) or if there are different opinions in the group.

Disagreements concerning comparisons have several different causes. 1) They can depend on the fact that different participants define dimensions and conditions in different ways. In this case, the solution is to create a common conceptual framework. 2) They can depend on the fact that the group does not have the sufficient know-how (see above). 3) They can also depend on the fact that participants actually have different opinions about the pair of conditions. If it is about the future, then it is not possible to solve this by gaining more knowledge. If it is about the present day and the short term, then it is a question of a normative comparison, i.e. what is allowed and what is not allowed to exist according to a few, more or less, pronounced criteria. In both cases, it is important to accurately document the disagreement, so that you do not get caught up in a futile discussion.

Step 2: Select configurations
Use the spreadsheet program to visualise the model and the configurations (figure 8).

Dimension A	Dimension B	Dimension C	Dimension D
a1	b1	c1	d1
a2	b2	c2	d2
a3	b3	c3	d3
a4		c4	
		c5	

Figure 8: A configuration must contain at least one condition for each dimension. Mark the conditions selected with a colour.

Facilitating the selection of configurations is all about creating meaningful "gestalts" of at least one condition from each dimension. There are several different ways of doing this. You can select two dimensions and allow combinations of them to be the core in the configurations.[39] Then, add conditions from the other dimensions. Another way is to first select two extreme scenarios, for example "worst case" and "ideal". Then, you add configurations between them. You can also just start at one end of the model and select conditions in the first dimension, then the second, and so on. If you have created a couple of configurations, then it is often quite easy to add more. Whatever you choose to do, make sure to check that the conditions go together with each other (preferably with the help of the cross-consistency matrix). If you have selected pairs of conditions that do not go together, you must select again.

Give the configurations names that reflect their gestalts. Preferably use exaggerated (and funny!) work names that you can then edit when the results are to be presented outside the group.

To consider:
Classic morphological analysis is based on pairwise relationships between conditions. We remove/dismiss the configurations that contain pairs that cannot coexist. However, sometimes it happens that combinations of three or more conditions are not consistent despite the fact that all the pairs in them can coexist separately. This is what we call the multilateral comparison. In its simplest form, the trilateral comparison, it looks like this:

[39] Resembles the GBN method's scenario cross. See, for example, The Rockefeller Foundation and Global Business Network (2010), "Scenarios for the Future of Technology and International Development", http://www.gbn.com/articles/pdfs/GBN&Rockefeller%20scenarios.technology&development.pdf

A+B = OK, A+C = OK and B+C = OK, but A+B+C = not OK. Be aware of this when you select configurations.

3.8.3 Examine the model and the configurations (synthesis)

There are good reasons for examining the model several times during the course of the work. By seeing the whole picture, you can further improve the model and create a balanced set of configurations. And it is often a good idea to sleep on it when working on wicked problems. Morphological analysis has a lot to do with going from “life, the universe and everything” to “nuts and bolts” and back again several times. Every time we do this, we become a little wiser, understand more about the problem and can choose a better level of description. A picture I usually use when examining the model is that of a painter who takes a step back to see the whole picture after having worked close to the canvas on the details.

In order to do this, you need to be able to visualise the whole. If you work with a spreadsheet program, print out all the configurations selected (like in Figure 7) on paper and lay them down next to each other prior to the examination. You should also have the model in basic form (with no configurations) and the cross-consistency matrix projected so that you can make changes when necessary.

When the group studies the model and the configurations, you, as a facilitator, should ask the group a number of questions:

- Does the result correspond with your intuitive idea of the problem?
- Are the configurations internally consistent?
- Are there any configurations missing?
- Should any of the configurations be removed?
- Is there a dimension missing?
- Can we combine any dimensions?
- Are there any conditions missing?
- Can we combine any conditions?
- Do the pairwise comparisons correspond with your opinion?

If the pairwise comparisons are individually OK, but the group still feels that there is something that does not add up, then there may be a dimension that is missing. In that case, add it and work through the model again.

If there are configurations that should not be there, despite the fact that the pairwise comparisons are OK, then perhaps one or more multilateral comparisons have slipped in.

Another thing to think about when examining the model is whether various types of information are found in the right place. Not all the information needs to be found in the dimensions or their conditions. Some of the information should be

found in the pairs of conditions in the in the cross-consistency matrix's relational database instead (see Documentation below).

3.9 Meta models

Meta models are images that I use in order to create structure on a general level. They can describe and define the system studied, illustrate model hierarchies and show how the external and internal environments are connected.

3.9.1 System description

With the help of the group, I usually sketch simple pictures of the system that we are studying on the board. This simplifies matters when we are to develop dimensions and helps the group to focus. The pictures need not be artistic to work. See for example figure 9, which is a sketch of a soldier and his boots, a study we made some years ago. The purpose of that study was to create a framework for standardising the purchase of special boots in a situation where certain units and individual soldiers and officers purchased a large number of different types of boots by themselves, since they were not satisfied with the standard boot.

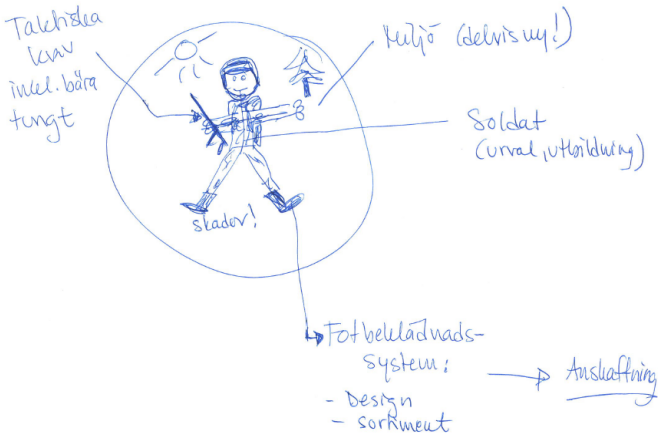


Figure 9: System description for Commando Soldier's Boots (actually a whole footwear system including socks and soles)

3.9.2 Hierarchical meta model

A good way of helping a group to see the whole picture in a morphological laboratory that consists of several different morphological models is to create hierarchical meta models, i.e. images of how the models are connected. An example can be found in figure 10.

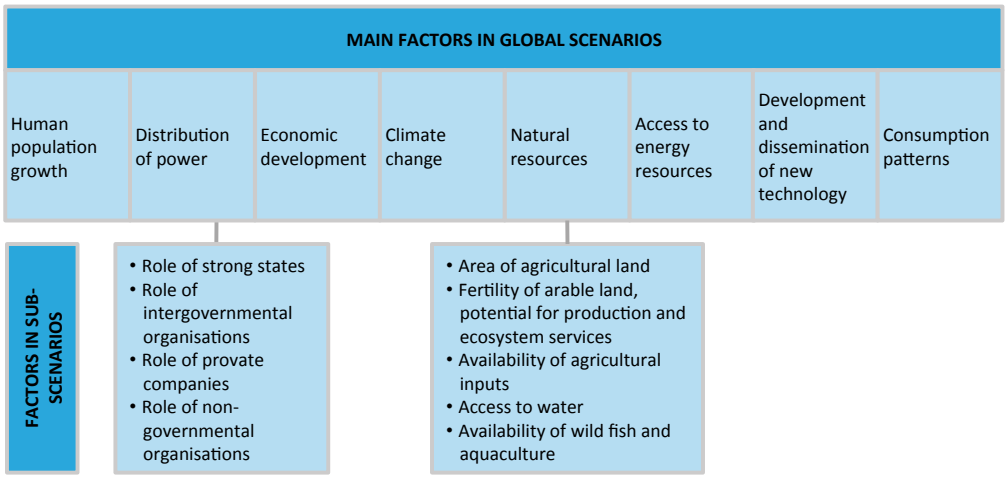


Figure 10: Meta model for Future Agriculture, Global scenarios. The scenario's dimensions are listed in the horizontal boxes. Two dimensions were described in more detail in separate morphological models (vertical boxes). For these dimensions the conditions in the main model were described by configurations in the sub-models. Read more in about this study in Chapter 4.2.

3.9.3 External/Internal environment models

A picture I usually use at the beginning of a process and sometimes during the diagnosis is what is known as an external/internal environment model (figure 11):

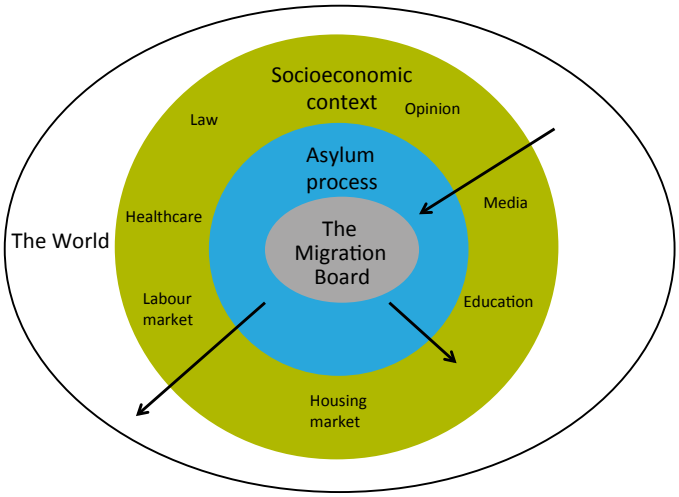


Figure 11: External/Internal environment model for a study about immigration with a focus on the asylum process. The arrows symbolises asylum seekers.

The internal environment consists of factors (dimensions) that the organisation studied can itself influence. In our example in figure 11 it is The Swedish Migration Board's own processes. The external environment consists of factors that influence the organisation, but that the organisation has no or too little influence over. In our example it is “The world” (where the asylum seekers come from) and the “Socio-economic context”. The transactional environment is the closest environment to the organisation, in this case, other stakeholders in the asylum process, for example the police and the municipalities. In this environment there is a mutual influence between the concerned organisations. By dividing the dimensions this way, we gain a practical structure with fairly large pieces to work with.

3.10 Documentation

3.10.1 During the workshop

All the dimensions and conditions that are not entirely self-evident need describing. The important thing is not to produce a stringent definition, but rather to describe what the group means by a certain concept. And to document it in the spreadsheet program and/or with the help of notes on paper or computer by the side. Sometimes, there is someone in the group who can take that responsibility, especially when working with matters that require expertise in order to evaluate what is said in the group.

In the relational database – a cross-consistency matrix – you put the justifications, examples, terms and conditions and criteria that are linked to the pairwise comparison. Use the spreadsheet program's comment function or write notes on the side. You can do this more or less comprehensively, depending on the purpose of the morphological analysis and the resources that are at your disposal.

3.10.2 Process reports

The better a workshop has been, the more confused the participants usually are. Thus, it is important to give them feedback and the opportunity to reflect between the work meetings. I therefore always write a process report after every workshop, which is also an important part of quality assurance. My process reports have the following headings:

- Introduction
- What did we do during the workshop?
- Results of the workshop
- Suggestions for continued morphological analysis
- What remains to be done?

Introduction
Background, purpose of the assignment, aim of the workshop, participants, date, place, focus issue.

What did we do during the workshop?
Summarise the work activities during the workshop. Indicate if anything notable happened, for example if a new model was established or if the focus issue was radically reformulated.

Results of the workshop
Here you should put in images of all the morphological models and meta models together with an explanatory text. You can put comments from Casper here or in an appendix. I usually edit the comments, set clear headings and clean up the text linguistically in order to increase readability.

Suggestions for continued work
A certain amount of back office work is often required in order to proceed, and it is important that all suggestions are based on what the group has done. If you make a new suggestion in the process report, you must explain your thought process behind your suggestion, which models/dimensions you used and which you chose not to use. The less time you spend with the group in relation to the wickedness of the problem, the more back office work you need to do to reach your goal.

What remains to be done?
Here, you make a list of continued work activities in the form of clear tasks where you specify what you will be doing during the coming work meetings and what is considered homework.
The process report should arrive within a week while the workshop is still fresh in the minds of the participants.

4 Examples

In this part, I present a number of examples on how we at FOI have worked with morphological analysis. In the first section, there are short pieces of text about different types of models that I have come across over the years. In the second section, there is a longer description of a morphological process.

4.1 Morphological models I have encountered

I put a great deal of thought into how I would typologise the morphological models that I have worked with. I finally fell for a model engineering structure since I believe that it is the most beneficial for those who wish to start working with the method. Here, I touch upon the simplest to the most complex type of laboratory:

- Simple laboratory
- Double laboratory
- Hierarchical laboratory
- Superposed laboratory

These examples are models that we have developed with the help of FOI's computer software, which makes it possible to visualise and study a large number of configurations in a short time. It is obviously difficult to do the same thing with a spreadsheet program, which lacks the automatic generation of all the possible configurations. See them therefore as a source of inspiration for your own way of applying morphological analysis and not as a “book of recipes”.

4.1.1 Simple laboratory

In its simplest form, the simple laboratory is a classic Zwicky “morphological box”. It has no inner structure, the dimensions are not sorted into a logical order. An example is the model we developed in order to study operational research methods (figure 12). Anything can be input and anything can be output here.

Information type	Mode of work	Validation	Study phase	Character of issue	Extent of 'back-office' work
Numerical	Individual analyst	Mathematical	Problem-formula-tion/structuring	Messes	Much
Graphic (non-numerical)	Small group of analysts	Experiment/ experience	Generation of alternatives (IF-THEN)	Problems	Moderate
Logical	Small group of analysts plus clients	Expert judgement	Analysis of possible solutions	Puzzles	Very little or none
Text/natural language	Large group of analysts plus clients	Belief/Faith	Interpretation, evaluation of result		
	Client/analyst network	Explicitly none	Presentation/ recommend		

Figure 12: A simple laboratory that we used to study methods within the Operational Research Methods project. The example shows the options available if you wish to study wicked problems ("messes") with a little amount of back office support from operational researchers, and wish to empirically validate the model.

The next level of structure is the existence of one or two conclusive dimensions. The most common is the Scenario dimension. An early example is the social scenarios we developed in 1998 for the Swedish Nuclear Fuel and Waste Management Co (SKB). The purpose was to investigate whether and how people in the future could have an impact on a deep geological repository for radioactive waste[40] (figure 13).

[40] Ritchey, T. and Stenström, M. (1998), "Samhällsscenarier om mänskliga handlingar som kan påverka djupförvar för radioaktivt avfall i långtidsperspektiv", FOA-R--98-00919-990--SE

Scenario	Knowledge about the repository	Level of knowledge and science	Purpose of interfering with the repository	Social development
The inclined plane	Widely known	Very high among the elite	To collect another resource or to build	Continuous
The collapse	Known among "the elite"	Generally much higher than today	To bring up the waste as a resource	Discontinuous
The recovery	Only known locally	As today	To check the repository	
Selective forgetfulness	Absent Inexistent	Lower than today	Mapping Inspection	
Unintentional impact due to forgetfulness			Sabotage	
Unintentional impact after collapse				

Figure 13: Simple scenario laboratory that explains on a social level why people can come into contact with radioactive waste in a deep geological repository within a 500-year time perspective (!)

Another example of a simple laboratory with two conclusive dimensions is the model we developed in order to study what the Swedish nuclear inspection's[41] new emergency preparedness would look like[42] (figure 14). The conclusive dimensions are Scenario phase and Preparedness level. The dimensions here are sorted chronologically from the starting point (scenario phase) to the choice of preparedness level. This example also shows how time series can be created for a scenario in a morphological model.

[41] The agency is now part of the Swedish radiation safety authority
[42] Stenström, M. (2004), "Morfologisk analys av SKI:s beredskap", SKI report 2004:37

Scenario phase	The security and timeliness of the information	What level of decision-making is required?	Demand for quality advice/ decision-making/Info	What cooperation is required?	What output data from SKI is required?	Primary recipient of output data from SKI	Level of preparedness
1 Information about problems at a facility in the vicinity of Sweden	High security Real-time	Jointly SKI and SSI	Well analysed and established advice/ decision-making	Cooperation with public authorities (person)	Supervisory decisions	Affected facility	Red
2 Fax with 'Alert' from the facility in question	High security Slight delay	Exclusively SSI	Detailed expert assessment	SKI on site in Sweden	Expert advice - external require-ment	SSI	Yellow
3 'Site area emergency' from the facility in question	High security Big delay	Exclusively SKI	Expert assessment (standard)	International assistance	Information - external requirement	The County Administrative Board	Green
4 'Facility emergency'	Low security Real-time	VB/TSI	Simplified analysis with expert support	Remote cooperation	Expert advice - own initiative	Central authorities	
5 'General emergency' - emission taking place	Low security Slight delay		Simple consideration	No cooperation is required	Information - own initiative	The police	
6 Measurements available	Low security Big delay				No output data is required	Municipal fire and rescue services	
7 Situation stabilised						Swedish Government Government Offices of Sweden	
						Sister agency abroad	
						Media	

Figure 14: Time series for the SKI scenario “Kärnkrafthaveri i Sveriges närområde” (Nuclear disaster in the vicinity of Sweden).

Another example of a simple scenario laboratory with a time series is the “road map” we developed for DP Sjö, a sub-project within the Swedish Armed Forces' and FMV's (Swedish Defence Materiel Administration) development project “Ledsyst M”[43] (figure 15).

Problem what?	How?	Who should do it?	What shall be developed?	Ready when?	Who receives the results?
Scenario & activities	Look for information	FMV	Bayesian net-work	Before the holiday	KRI Led
Incoming threat	Model	Ledsyst M	Morphological field	Before week 34	Ledsyst T
Own players/ objects included	Play	DP Sjö	System description	Before week 36	Ledsyst M
Grades of fires	Simulate	FOI	Compilation of information	Weeks 36 - 37	DP Sjö
Typical situa-tions		FHS	New knowledge about Joint Fires	Week 38	
Components of manage-ment approach		External con-sultants		Weeks 39 - 40	
Grades of jointness				After week 40	
Measuring rod effect (Def. of the outcome)					
Evaluation of effect method Joint					
Interpret and analyse					

Figure 15: Road map for the “DP Sjö” project

[43] FM Ledsyst was a big project concerning the development of command and control systems within the military defence. Ledsyst M is about command and control methods. The focus issue for our study was: Formulate hypotheses and draw conclusions about when it is best to use joint combat against maritime targets and what requirements the joint combat places on the management method.

4.1.2 Double laboratory

In a double laboratory, there is an inner structure in the form of two separate perspectives, often external environment and internal environment. There are many examples of this type of model. Here, I choose to present the model for evaluating the municipal fire and rescue services' preparedness for chemical accidents, which we developed on behalf of the Swedish Rescue Services Agency. We worked alternately with both of the perspectives before putting them together in a common model, figures 16 and 17.

Planning and cooperation	Training and exercises	Staffing	Equipment	Management	Response to the source	Response to those affected	Response with information
Object-bound planning and cooperation exercises	Basic training and frequent exercises for class of substance	11 or more	Customised equipment for class of substance in	4 people	Collect or seal within 15 mins	Help many people within 30 mins	Warning within 5 mins
Planning for class of substance in question	Basic training and intermittent exercises for class of	8-10	Basic preparedness for class of substance in	3 people	Collect or seal within 30 mins	Help individuals within 15 mins	Warning within 30 mins
Standard procedure for class of substance in	Basic training and intermittent general exercises	5-7	Less than basic preparedness for class of substance in	2 people	Reduce by maximum 50% within 15 mins	Help individuals within 30 mins	No action within 30 mins
General standard procedure for chemical	Basic training	4 or less		1 person	Reduce by maximum 50% within 30 mins	No help within 30 mins	
No standard procedure for chemical					No action within 30 mins		

Figure 16: Double laboratory. This is the "VIK"[44] evaluation instrument. It has been used by Sweden's municipalities in order to work out what can be considered reasonable local preparedness for chemical accidents. The green field shows the dimensions that describe the resources of the fire and rescue services. The turquoise field is an operations scenario – in this case, emissions of toxic compressed gas. We compiled four different scenarios to combine with the resource module.

[44] VIK is a Swedish acronym for Evaluation Instrument for Chemical accidents

Planning and cooperation	Training and exercises	Staffing	Equipment	Management	Response to the source	Response to those affected	Response with information
Object-bound planning and cooperation exercises	Basic training and frequent exercises for class of substance	11 or more	Customised equipment for class of substance in	4 people	Collect or seal within 15 mins	Help many people within 30 mins	Warning within 5 mins
Planning for class of substance in question	Basic training and intermittent exercises for class of	8-10	Basic preparedness for class of substance in	3 people	Collect or seal within 30 mins	Help individuals within 15 mins	Warning within 30 mins
Standard procedure for class of substance in	Basic training and intermittent general exercises	5-7	Less than basic preparedness for class of substance in	2 people	Reduce by maximum 50% within 15 mins	Help individuals within 30 mins	No action within 30 mins
General standard procedure for chemical	Basic training	4 or less		1 person	Reduce by maximum 50% within 30 mins	No help within 30 mins	
No standard procedure for chemical					No action within 30 mins		

Figure 17: This is how to use VIK: Choose the conditions in the resource dimensions that best describe the municipality's fire and rescue services. The outcome is the preparedness available for handling a chemical accident. You can also do the opposite: choose a preparedness level and see what resources it requires.

4.1.3 Hierarchical laboratory

A hierarchical laboratory contains a main model and one or more simple models that each describes a dimension in the main model. Thus, this is a technique for being able to include many details without having to create big models. An example is strategies for a public housing company (figure 18). We have conducted many studies that have resulted in hierarchical laboratories, Scenarios for Future Agriculture (see 4.8) and many military studies, for example the modernisation of Combat Vehicle 90 and Combat Boat 90, the future ground combat soldier “MARKUS”, future anti-aircraft warfare and tactical UAVs.

The City's housing market	The City's economic development	Housing rents	Procurement of capital	Contribution to population growth (company	New production (company strategy)	Maintenance of the housing stock (company strategy)
Attractive City	Prosperous times	Increases 5%/year	Possibility to leverage & manage stock	Exclusive accommo-dation	150 apartments/ year	Develop
Today's trend prolonged	Today's trend prolonged	Increases 4%/year	Possibility to leverage Marginal stock management	New production normal cost	50 apartments/ year	Renew, improve
Stagnation in the City	Today's trend + Selling off (political decision)	Increases 3%/year	End to leveraging Stock management	New production low cost	20 apartments/ year	Protect value
Move out from the City	The tenants' dream	Increases 2%/year	End to leveraging Marginal stock management	Urban renewal	No new production	Patch and repair
	Stagnation	Increases 0-1%/year		Broadband		
				Guaranteed accommodation for students		

The City's housing market	Population 2010	More attactive living than today	Less attractive living than today	Competition from non-rental living	Vacancies
Attractive City	100 000 inh	City/ Waterfront	City/ Waterfront	More	1% free appartments
Today's trend prolonged	97 000 inh	For youth/ students	For youth /students	SQ	3% free appartments
Stagnation in the City	94 000 inh	Commuting distance	Commuting distance	Less	6% free appartments
Move out from the City	91 000 inh (as today)	For seniors	For seniors		
	88 000 inh	New production low cost	New production low cost		
		Tradional family	Tradional family		
		Mass production	Mass production		
		Periphery	Periphery		

The City's economic development	Required rate of return	Housing rents	Procurement of capital	Interest rate and inflation	Government support to new production	Environmental demands on housing market
Prosperous times	7% revenue, no yield	increases 5%/year	Possibility to leverage & manage stock	Low stable	High	Slow moderate increase
Today's trend prolonged	7% revenue, yield	increases 4%/year	Possibility to leverage Marginal stock management	Low increasing	Low	Increasing over time
Today's trend + Selling off (political decision)	5% revenue, no yield	increases 3%/year	End to leveraging Stock management	Fluctuations Unstable		Fast increase
The tenants' dream	5% revenue, yield	increases 2%/year	End to leveraging Marginal stock management	High increasing		
Stagnation		increases 0 - 1%/year				

Figure 18: Hierarchical laboratory. This was a job that we did for a public housing company. The purpose was to support a dialogue about vision and strategies between the management team and the board. The two lower models each describe a dimension in the upper model.

Another example is a scenario-strategy study that we carried out for the Swedish Ministry of the Environment's inquiry on producer responsibility.[45] The assignment was to test strategies against a few different future scenarios in order to see how robust they were. Here, we had two different expert groups that initially worked independently on a perspective each (figure 19 and 20).

[45] Stenström, M., Ritchey, T. (2004), "Scenarios and Strategies for Extended Producer Responsibility Using Morphological Analysis to evaluate EPR System Strategies in Sweden", FOI, foi.se/ma

SCENARIO	Buyer behaviour	Consumption and private import	Consumer behaviour waste separation	National environmental policy	Price of new raw material and recycled material	Technological development: Use of materials	Technological development: Recycling	EU regulations on the import & export of waste
World crisis	Environmentally-friendly products, any prize	Both up	Separates everything voluntarily	At the forefront Holistic thinking Legal/Economic	High price raw High price recycled	Much less material than today	Increases quickly	Freer than today
Shortage of raw materials	Environmentally-friendly products, if low prize	Consumption: SQ Private import: up	Separates if rewarded	At the forefront Non-holistic thinking Only legal	High price raw Low price recycled	Less material than today	Increases	As today
As today with environmental stagnation	Ignores environmental aspects	Consumption: up Private import: up a bit	Separates if forced	At the forefront Willingness	Low price raw High price recycled	Approximately as today	Marginal development	More restrictive than today
As today with strong environmental policy		Consumption: SQ Private import: up a bit	Separates as he or she sees fit/Protests	EU adaptation	Low price raw Low price recycled			
The Greenhouse: Away from combustion								
High-tech								
Demateriali-sation								
Green market								

Figure 19: Scenarios for producer responsibility. With eight scenarios, we covered all the conditions except for two.

Market for the processing of waste	Legal framework	Treatment	Source separation system	Environmental adaptation of products	Collection system	Recycling technology	Environmental information	Vision
International	Unconstrained Industry rules (mature market)	Recycling up Raw material source for energy down	> 15 commodity fractions	Focus on clean material	Close to property	Mechanical	Chemicals Material Energy	A
National/Inter national surrounding area	General state requirements: Individual No monopolies	Recycling up Raw material source for energy up	> 15 material fractions	Same mix as today	Pick-up system High frequency	Thermal	Chemicals Material	B Reference
Local/regional	General state requirements: Collective Some mono-polisation	Recycling down Raw material source for energy up	As today	Focus on reduced amounts of material	Pick-up system Low frequency	Chemical	Chemicals Energy	C
	Detailed state requirements: What and who?	Landfilling increases, relatively speaking	< 5 commodity fractions			Biological	Chemicals	
			< 5 material fractions					

Figure 20: The strategy perspective. The strategies were referred to in this study as “vision”.

Next, we created a scenario-strategy laboratory by adding “vision” as a dimension in the scenario model (figure 21). We finally compared the three visions to all the conditions of the scenario dimensions. Both groups took part in this work. We had the three visions on paper as support in the comparison (example: vision C in figure 20).

Scenario	Buyer behaviour	Consumption and private import	Consumer behaviour regarding waste separation	National environmental policy	Price of new raw material and recycled material	Technological development: Use of materials	Technological development: Recycling	EU regulations on the import & export of waste	Vision
World crisis	Environmentally-friendly products, any prize	Both up	Separates everything voluntarily	At the forefront Holistic thinking Legal/Economic	High price raw High price recycled	Much less material than today	Increases quickly	Freer than today	A
Shortage of raw materials	Environmentally-friendly products, if low prize	Consumption: SQ Private import: up	Separates if rewarded	At the forefront Non-holistic thinking Only legal	High price raw Low price recycled	Less material than today	Increases	As today	B Reference
As today with environmental stagnation	Ignores environmental aspects	Consumption: up Private import: up a bit	Separates if forced	At the forefront Willingness	Low price raw High price recycled	Approximately as today	Marginal development	More restrictive than today	C
As today with strong environmental policy		Consumption: SQ Private import: up a bit	Separates as he or she sees fit/Protests	EU adaptation	Low price raw Low price recycled				NONE
The Greenhouse: Away from									
High-tech									
Dematerialisation									
Green market									

Figure 21: Finished scenario laboratory for the producer responsibility inquiry. The result of the comparison showed, for example, that C was the vision that worked in most scenarios.

4.1.4 Superposed laboratory

In a superposed laboratory, we create a relationship between the external environment and the internal environment by describing them with the same dimensions. In one case, it is “the external environment's requirements on capability” and in the other, “the internal environment's capability”. We do not compare the internal environment and the external environment to each other directly, but rather only to the common dimensions. This provides a compact laboratory where we can quickly see what systems work in what external environment and what systems are required by a specific external environment. We have not worked with very many superposed laboratories, but they have proved to be extremely effective in their (military) context. I present the UAV tactical level as an example (figure 22 and 23). The aim of the study was to broadly examine the types of UAVs that could be of interest on a tactical level in the Swedish Armed Forces.

Micro scenario	Requirements on/ Operating capability	Information environment	Environmental requirements/ Environmental properties	Requirements on/ The service's reaction time	Requirements on/ Endurance in operation	Requirements on/ Survival ability	UAV system
Armed combat Mechanised brigade	Combat Release bombs Supply robots	Free access to the network	Operate during the day	Seconds	Continuous	Evade/resist aerial combat	Markus
Armed combat Tank company	Combat Be robot	Communication with superior	Operate in darkness	A few minutes	Frequent and long operations Day	Evade/resist ground combat 1,500-5,000 m	Stor-Bure
Urban combat Urban infantry platoon	Combat Launch grenades	Local info acquirement	Operate in rainfall	15 minutes	Frequent and short operations Day	Evade/resist ground combat under 1,500 m	Urban
Border control Reconnaissance battalion	Combat electronically Interfere	Completely cut off Info only within own system	Operate in particle-rich environment	Hour	Frequent and short operations Hours	Resist electronic combat	Batman Classic
Terrorism airport NBC company	Point out Identify/classify		Operate in strong wind	A few hours	Infrequent and short operations Day	No requirements No capability	Kerberos bas
Search Home Guard	Specify position Classify/Identify		Operate in increasingly icy conditions	Day	Infrequent and short operations Hours		Diana
"The UAV war"	Explore Discover				Infrequent and long operations Day		Mephisto
	Link within own system				Infrequent and long operations Hours		Aerosonde
	Link for other systems						
	Transport						

Figure 22: Superposed laboratory created in the UAV tactical level study. Here, we have described the scenario (i.e. the micro situation) using the same dimensions as the UAV system – in the former case, in terms of requirements on the system, and in the latter case, in terms of qualities of the system. The figure shows the micro situations that the "MARKUS" system can handle. The systems required in order to handle a certain micro situation can be shown in the same way.

Micro scenario	Requirements on/Operating capability	Information environment	Environmental requirements/ Environmental properties	Requirements on/The service's reaction time	Requirements on/Endurance in operation	Requirements on/Survival ability	UAV system
Armed combat Mechanised brigade	Combat Release bombs Supply robots	Free access to the network	Operate during the day	Seconds	Continuous	Evade/resist aerial combat	Markus
Armed combat Tank company	Combat Be robot	Communication with superior	Operate in darkness	A few minutes	Frequent and long operations Day	Evade/resist ground combat 1,500-5,000 m	Stor-Bure
Urban combat Urban infantry platoon	Combat Launch grenades	Local info acquirement	Operate in rainfall	15 minutes	Frequent and short operations (every 10 mins) Day	Evade/resist ground combat under 1,500 m	Urban
Border control Reconnaissance battalion	Combat electronically Interfere	Completely cut off Info only within own system	Operate in particle-rich environment	Hour	Frequent and short operations (every 10 mins) Hours	Resist electronic combat	Batman Classic
Terrorism airport NBC company	Point out Identify/classify		Operate in strong wind	A few hours	Infrequent and short operations (once/3 hours) Day	No requirements No capability	Kerberos bas
Search Home Guard	Specify position Classify/Identify		Operate in increasingly icy conditions	Day	Infrequent and short operations (once/3 hours) Hours		Diana
"The UAV war"	Spy out the area Explore/discover				Infrequent and long operations (once/3 hours) Day		Mephisto
	Link within own system				Infrequent and long operations (once/3 hours) Hours		Aerosonde
	Link for other systems						
	Transport						

Figure 23: The same model, showing which systems that can handle the micro situation "Urban combat Urban infantry platoon"

4.2 Example of a morphological process: Scenarios for Future Agriculture

4.2.1 Introduction

This is probably the finest example of a scenario laboratory that I have been involved in creating. What is more, we had a very enthusiastic, committed and able work group that made the work extremely fun, even if not completely headache-free. What was quite special about this assignment was that the tender dialogue took a long time – we were obviously communicating with other researchers… They wanted to understand in detail what they were getting themselves into and this was a huge advantage when we finally got started on the work.

The purpose of the assignment was to support the Swedish University of Agriculture Sciences (SLU) in its mission to develop future scenarios within the framework of the Future Agriculture research investment.[46] Figure 24 below illustrates how the programme group regards the research initiative and how it should work.[47] (The Flower symbol was created during our work on the scenarios).

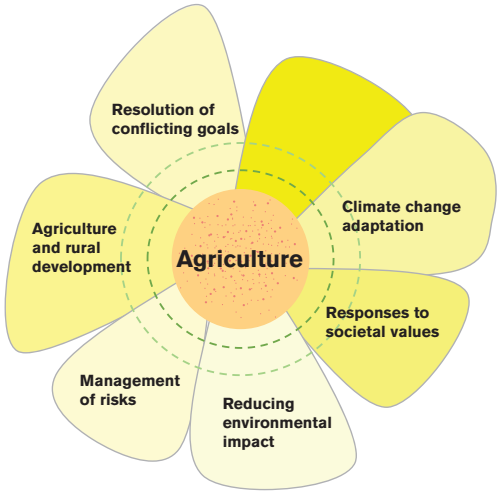


Figure 24: Illustration of the Future Agriculture research initiative.

Two FOI colleagues worked with me on this study.

[46] www.slu.se/framtidenslantbruk, 18-05-2011
[47] www.slu.se/sv/centrumbildningar-och-projekt/framtidens-lantbruk-/om-framtidens-lantbruk/, 18-05-2011

4.2.2 Process and results

We had a two-day work meeting booked in from the beginning in order to develop a framework for scenarios that would be used to identify research issues concerning future food production and land use. SLU would then write scenario texts and, with the support of FOI, conduct two seminars with stakeholders and researchers in order to gather ideas for research issues. Using this as a basis, we would then have another two-day work meeting to bring everything together.

At the end of the first meeting, we were able to ascertain that an additional two-day work meeting would be required in order to develop the scenario framework. At first, we thought about exchanging FOI's participation in the idea seminars with an extra work meeting, but in the end, SLU expanded the assignment instead.

In addition to the work meetings and seminars, we had three meetings with the head of the programme and the programme secretary for Future Agriculture. The purpose of these meetings was to process the results together and make suggestions on model structures and methods of working for the continued work in the group. During the entire study, we had close contact with them via telephone and e-mail.

4.2.2.1 What is the aim of all this?

We met the work group for the first time at the end of November 2009. It was an illustrious gathering: professors of ecology, farming systems, reproduction in domestic animals, domestic animal genetics and crop production ecology and experts within national economics and demographics. After presenting morphological analysis, we began formulating a focus issue.[48] This is what its first version looked like:

What is the best way to describe the external environment that SLU's research on land use and food production should prepare us to confront through the adaptation to or change of the external environment within a time perspective of 25-50 years?

This was the start of a discussion about what the scenarios should represent, an issue we wrestled with during the entire study. Should they be best/worst case scenarios that research is helping to achieve/avoid? Or should they be future conditions that the research on land use and food production helps to make as good as possible once the scenario has occurred? We opted for the latter question and, during the third work meeting, we formulated the following programme description:

[48] We brought along a suggestion to the first work meeting.

The scenarios must be conceivable, neutral future projections that illustrate various problems and opportunities. They must not be dream scenarios or disaster scenarios. The time perspective for the scenarios is 2050. It is long enough to achieve major changes in land use and food production, and for ensuring a generation change in the research community. It is also short enough to affect those of us alive today. The geographical perspective should be partly global, partly regional.

The final version of the focus issue was as follows:

How can research contribute to environmentally, economically and socially sustainable food production and land use in various conceivable scenarios?

4.2.2.2 The scenario laboratory

From a morphological point of view, this study mostly dealt with problem structuring. Knowledge and ideas were in abundance. It was only a matter of creating a functional scenario laboratory and developing a few good future scenarios from it. However, it proved it was not just that....

The result of the first work meeting was a somewhat functional model and three sketches where we had gathered together dimensions that were just about connected:

1. Total model
2. Production factors
3. Consumption
4. General factors

1. Total model from a geographical perspective (figure 25)
This model includes some dimensions from the other models. They looked a little bit different for different regions. We tried to develop scenarios for India-China, North America and Sweden.

2. Production factors (figure 26)
This model describes agriculture from a number of perspectives. We did not have the chance to do a lot more than just gather them together in a model.

3. Consumption (figure 27)
This model describes the consumption of food and land use. We made evaluations of pairwise consistency in this model.

4. General factors (figure 28)
In this model, we gathered together all the dimensions that describe the world in which food production, land use and consumption exist.

Scenario India-China	Economic growth	Population growth	Agricultural production	Consumption of fossil fuels	Consumption of food (predominant)	Consumption of finite resources (nutrients)	Impact on the climate from India-China	Environmental impact (excl. climate) India-China	Infection spread (animals and plants) from India-	Migration India-China
Asia powerful in the world	High	Exponential	Small agricultural production	Much higher per capita	Meat from ruminants Milk products	Very large proportion of the world's phosphorus and nitrogen	Very large	Large-scale ecological collapses	Better infectious disease control than today	Large immigration to China
Isolated and short-term	Medium	Linear	Large agricultural production	Higher per capita	Pork and poultry	Large proportion of the world's phosphorus and nitrogen	Large	Local ecological collapses	Local infection Local consequences	Large amount of mobility within India-China
Scarcity	Low	Declining growth towards the asymptote		As today	Aquaculture (fish and shellfish)	Small proportion of the world's phosphorus and	Lowest possible level	Acute shortage of water	Between animals/plants globally	No large population movements in India-China
		No growth		Very little globally	Vegetable-based protein			Lowest possible level	Zoonoses globally	Regionalisation New borders
					Carbohydrates					

Figure 25: Total model from a geo-graphical perspective

Region	Scenario General factors	Type of land	Company structure agriculture	Ownership agriculture (land)	Level of knowledge agriculture	Application of technology within agriculture	Application of biotechnology within agriculture	Use of nutrients	Use of water in agriculture	Handling of disease and pest control (animals and plants)
Sweden	A	Arable land	Industrial farmer	The farmer owns	High	Unpredictable leaps in technology	Cell culture	Large export	Advanced cycle	Discontinue current plant/ animal production
Europe	B	Pasture	Agricultural enterprise with employed workforce	Farm lease	Low	Bio/physiology system high-tech	Advanced genetic improvement	Advanced cycle	Groundwater irrigation	Control measures
India-China	C	Forest land	Family farm		Uneducated	Precision agriculture	Traditional genetic improvement	Linearly Large import	Surface water irrigation	Preventative measures
North America	D	Marginal land	Part-time farmer			Mechanisation	Vaccine development		Water harvesting	Acceptance of low levels of attack
South America		Wetlands				Unmechanised	High-tech biological pest control/ stimulation		Rainfall	No action
Sub-Saharan Africa										
Medi-terranean Middle East										

Figure 26:
Production factors

Scenario	Region	Income	Economic growth	Population, number	Population, ages	Consumption of food more than today...	'Public goods' nature	Values, consumption food and environment	Values lifestyle agriculture
2064 'best outcome'	Sweden	Large middle class	High	Exponential	Hourglass	Meat from ruminants	Clean water Clean air	Produced locally	Urbanised lifestyle
2064 'worst outcome'	Europe	Mass poverty	Medium	Linear	Pyramid with broad base	Milk products	Areas with walking trails (right of public access)	Environmentally smart	Urban garden
Sweden 2009	India-China		Low	Declining growth towards the asymptote	Pyramid with narrow base	Pork and poultry	Hunting Fishing	Animal ethics	New green wave
	North America			No growth	Inverted pyramid	Aquaculture (fish and shellfish)	Wilderness	Human ethics	Agricultural contractor - the best you can be
	South America			Decreasing		Vegetable-based protein	Open landscape	Climate smart	Farming is a low status occupation
	Sub-Saharan Africa					Carbohydrates	Adventure complexes	GMO-free	
	Mediterranean Middle East					Vegetables	Carbon sink	Exotic is nice	
						Fruit	Biodiversity	Food must not take time	

Figure 27: Consumption

Scenario General factors	Region	Access to fossil fuels	Access to non-fossil energy	Transport patterns	Access to finite resources (nutrients)	Global power relations	Transregional and intraregional networks and migration	Laws, rules for trading	Spread of infection (people)	Climate	Access to water
A	Sweden	Very good	Very good	Global	Very good	Democracy dominates	High mobility to region	International consensus high level of protection	Better infectious disease control	Climate scenario 1 (mitigation 1-2 oC)	Surplus of water
B	Europe	Good	Good	Intraconti-nental	Good	Focus Pacific Ocean	High mobility within region (urbanisation)	International consensus low level of protection	Local infection Local consequence	Climate scenario 2 (5-6 oC)	Sufficient
C	India-China	Very little	Very little	Regional	Very little	Big conflict in the Middle East	High mobility within region (decentralisation)	Regional trading blocs	Pandemics increase	Climate scenario 3	Uneven access
D	North America					Global conflict Resource scarcity	High mobility from the outside	National protectionism		Climate scenario 4	Severe shortage
	South America						Low mobility within region				Acute water shortage
	Sub-Saharan Africa						Low mobility to region				
	Medi-terranean Middle East										

Figure 28:
General factors

After the first work meeting, we had a total of four models with no particular context. We had started to create a total model and tried to develop some scenarios. However, we were far from reaching our aim – a complete scenario laboratory. The confusion was huge to say the least. But if, like me, you have done this before, then you know that it will work out in the end. The good news was that we had created a large number of dimensions with which to proceed. Furthermore, SLU had already decided at the end of the first work meeting to set aside an additional two days for developing the scenario laboratory. Then it was simply a case of rolling up our sleeves!

Between work meetings one and two, we also had two meetings with the small SLU group and even allocated some of our own time to thinking about structure and limitations. We created a scenario laboratory that looked like this (figure 29):

GLOBAL FACTORS					REGIONAL FACTORS				
Global Relations of power	Global Population	Global Economic develop-ment	Global Resources	Global Climate	Region	Regional Population	Regional Economic develop-ment	Regional Resources	Regional Climate

Figure 29: The scenario laboratory consisted of one main model, Scenarios with global and regional perspectives. Some of the dimensions were described in more detail in sub-models (green boxes).

We now had a main model that included a global perspective and a regional perspective. We then had three sub-models that were to describe the population (global and regional), economic development (global and regional) and access to resources (global and regional) dimensions. Together, we had also formulated a clearer objective for the scenario development: “Develop 4-6 scenarios that describe possible futures that are significant to how we produce food and use land. The scenarios must provide conditions for future land use”.

During the second meeting, with the help of the laboratory, we wanted to develop scenarios for different regions – which was what we did. But first we reviewed the models and made certain changes. This resulted in four models that we used for developing six scenario frameworks (which later became five when SLU wrote texts about them). Figure 30-34 illustrates the models and frameworks (the morphological configurations) for the scenario “Asia powerful in the world” (it was later renamed “Changed balance of power”). Thereafter we present the scenario texts that were written based on the frameworks.

Scenario	Access to resources, global scenarios	Global power relations	Population, global scenarios	Economic development, global scenarios	Global climate scenarios (2100)	Population, regional scenarios	Agricultural policy	Regional power relations	Economic development in Europe	Access to resources, regional scenarios	Regional climate scenarios
An overexploited world/West	Maximum pressure on land resources	Fragmentation	Slower growth 8 billion 2050	High North Low South	Type B1 (min impact) 1.5oC	EU business as usual	EU in the global economy Deregulation	Strong region (supra-nationalism)	Balanced development in Europe	High ambition with regard to the climate and environment	Lower span
Biological production is the base	Minimum pressure on land resources	Unipolar world order East	UN Population Division 9 billion 2050	Low North High South	Type A230C	Fortress Europe falls	EU protected market As today	Strong nation states	Economic balance of power as today	Follows global trend	As expected according to IPCC
A happier world	Scrub invasion Low ambition with regard to the climate and environment	Unipolar world order West	Faster growth 11 billion 2050	Low North Lower South	Type A1F1 (max impact) 4oC	New green wave	National agricultural policy	Weak states Weak supra-nationalism	Stronger east Weaker south	Low ambition with regard to the climate and environment	Upper span
Asia powerful in the world	High ambition with regard to the climate and environment	Regional protectionism		High North High South		Self-sufficient EU	Reliable global agreements				
The world recovers its senses		MA: Adapting mosaic									
An overexploited/ fragmented world											

Figure 30: The main model (overall scenarios for global and regional levels), main scenario “Asia powerful in the world”

Power relations global scenarios	The role of large (strong) state players	Supranational institutions that influence the food supply	The role of private commercial players	The role of non-state (political) players
Fragmentation	USA dominates	Strong globally	Stronger than today	Strong
Unipolar world order East	Multipolar	Functioning globally	As today	As today
Unipolar world order West	China-India dominate	Functioning regionally	Weaker than today	Weaker than today
Regional protectionism	No strong state player	Weaker than today		
MA: Adapting mosaic				

Figure 31: Global power relations, sub-scenario “Unipolar world order East”

Access to resources, global scenarios	Potential global cultivated and grazed land	Soil fertility Production potential Ecosystem services	Global water	Fishing and aquaculture	Access to agricultural inputs	Global energy
Maximum pressure on land resources	Area as today, situated as today	Increased	Access to water as today, distributed as today	Access to wild fish as today	Good Low prices	A2: Biofuel with fast technological development
Minimum pressure on land resources	Area as today displaced towards the polar regions	As today	Access to water as today, more unevenly distributed	Less access to wild fish. Aquaculture makes up the difference	Little High prices	B2: Fossil with strong climate policy
Scrub invasion Low ambition with regard to the climate and environment	Area as today displaced towards the equator	Decreased	Deteriorated quality, distributed as today	Less access to fish		A1: Fossil with weak climate policy
High ambition with regard to the climate and environment	Increased area		Deteriorated quality, more unevenly distributed than today			B1: Fossil is cheap

Figure 32: Global access to resources, sub-scenario “Scrub invasion…”

Population, regional scenario	Housing patterns in the region	Consumption patterns (dominant)	Population growth in the region	Demographics in the region
EU business as usual	High urbanisation Functioning infrastructure	Animal-based food (ruminants)	Approximately as today (more developed)	Even (more developed)
Fortress Europe falls	High urbanisation Semi-rural	Animal-based food (predatory fish, pork, poultry)	50% increase (less developed)	Pyramid with broad base 1 (less developed)
New green wave	Urban concentration	Limited amount of animal products Vegetable-based food		
Self-sufficient EU	Urban sprawl			
	Developed rural areas			

Figure 33: Regional population, sub-scenario “EU business as usual”

Population, regional scenario	Housing patterns in the region	Consumption patterns (dominant)	Population growth in the region	Demographics in the region
EU business as usual	High urbanisation Functioning infrastructure	Animal-based food (ruminants)	Approximately as today (more developed)	Even (more developed)
Fortress Europe falls	High urbanisation Semi-rural	Animal-based food (predatory fish, pork, poultry)	50% increase (less developed)	Pyramid with broad base 1 (less developed)
New green wave	Urban concentration	Limited amount of animal products Vegetable-based food		
Self-sufficient EU	Urban sprawl			
	Developed rural areas			

Figure 34: Regional population, sub-scenario “Fortress Europe falls”

Scenario text for "Changed balance of power"[49]

Population growth is relatively low. The balance of power has moved from the West to China and India, countries whose economies are developing fast. Economic development is weaker in Europe. Political ambitions regarding climate and the environment are low. A marked increase in global warming results in that the main agricultural areas are moved towards the north and the equator where rainforest is being felled.

Global

Economic growth in Asia is very strong while it is weaker in the Western world. Population growth is lower than the UN's forecast. This is mainly because of increased standards of living in some of the bigger and more populous countries. In 2050 the world population is 8 billion. China's ambition and expansion has resulted in a change in the world order. Power has moved from the West to China and other large countries, such as India. A condition for this altered balance of power is that the UN and intergovernmental institutions like the World Trade Organisation (WTO) and the World Bank are able to influence nations. Private commercial actors are also relatively powerful (similar to today), while non-governmental, non-commercial actors, for example religious movements and human rights and environmental organisations, play a less important role in global development.

The world economy is characterized by deregulation and free trade. In many Asian countries standards of education are high and technological advances very rapid. Poorer education in the West and continuing slow development in many African countries result in uneven distribution of new technology around the world. There is a sharp rise in the global temperature (3-4 °C), which leads to rising sea levels, intense heat waves and frequent heavy rainfall. Despite such marked climate effects, environmental objectives are comparatively low on the political agenda. Economic growth is linked to short-term solutions designed to meet the needs of the day rather than those of future generations.

Supplies of fossil fuels, especial coal, are still plentiful. Fuel is relatively cheap because its use is not regulated at a political level. Consequently, only a small proportion of agricultural land is used to grow bioenergy crops. Global trade in food products is based on energy-intensive transport systems.

The total area of arable and grazed land is approximately the same as today, but climate change, with severe drought in large areas, has resulted in the

[49] Öhborn et. al., Five Scenarios for 2050 – Conditions for Agriculture and Land Use, SLU, Future Agriculture 2011

displacement of agriculture towards the north and south poles and the equator. In regions with plentiful rainfall around the equator, rainforest has been cleared to make way for arable land. Availability of agricultural inputs (e.g. phosphorus) is still adequate and inputs are relatively cheap because they are not the target of environmental policies. Fertility and production potential of agricultural soils diminishes as a result of weak environmental policies leading to extensive use of pesticides and low quality chemical fertilizers. This also results in decreased availability of ecosystem services, such as water purification, and pollination because of the decline in numbers of some insects.

Climate change and environmental problems lead to an acute shortage of clean water in many regions. Availability of water is very unevenly distributed. Use of fossil fuels results in large emissions of carbon dioxide causing acidification of the oceans. Emission of different types of pollutants, acidification and overexploitation of fish stocks lead to the collapse of marine ecosystems, and availability of wild fish decreases. However, at the same time, aquaculture is being developed and therefore availability of fish for consumption remains unchanged. Plant-based food makes up 75 % of global consumption calculated in calories and consumption of animal-based products is therefore on average higher than today. This increase, a result of improved living standards particularly in Asia, leads to a reduction in malnutrition and improved conditions for development in many areas.

Europe

The search for work and improved living standards leads to a large wave of migration to Europe. The number of people living in Europe therefore rises dramatically (by just over 20 %) and immigration means a plentiful supply of labour. The average age of the population is low. The economy is weak and people are mostly concerned about the struggle to have a good life today; few take active responsibility for the needs of future generations. The rapid climate change, e.g. rise in temperature, leads to large numbers of climate refugees in the world. Because they are not given asylum by the strong countries of Asia, these refugees find their way to Europe.

However, Europe has some kind of supranational organisation that prevents uncontrolled immigration. This organisation also acts as a common European negotiator with the stronger economies. Deregulation means that there are no agricultural subsidies or any strong regional policies for Europe. The balance of power has also changed in Europe. The Mediterranean region has a weaker economy due to intense drought while Eastern Europe benefits from, among other things, extremely fertile soils and becomes economically stronger. In these countries education standards improve in contrast to the rest of Europe where standards decline.

Climate change in Europe follows the global trend, in other words temperature rise is high. The effects of a change in climate are obvious, but the political will to

reduce or slow down warming decreases as the European economy becomes weaker. There are still plentiful supplies of fossil fuels (especially coal) which are relatively cheap. The land area used for production of food and animal feed as well as grazing is approximately the same as today, but it has shifted to the north where availability of water is better. Arable land is exploited more intensively than today (e.g. more than one crop harvested per year) and disused arable land is being brought back into use. Availability of inputs in Europe follows the global trend; there is a plentiful supply at relatively low prices. Thus, soil fertility and production potential in Europe remain on average at the same level as today. Technological developments within agriculture are slow.

Availability of clean water is relatively low and water resources are unevenly distributed. Availability of wild fish has also declined and this is compensated for in Europe by increased aquaculture. European fish consumption thus contributes to a further collapse of the oceans' fish stocks. In this scenario urbanization is high and migration occurs both to large cities and smaller towns that are growing fast. Many people commute to work. The countryside is being rapidly depopulated, particularly those areas suffering from drought. There is a working infrastructure throughout Europe, but interest in rural issues is low.

Food consumption consists (like today) of 30 % animal-based and 70 % plant based foods calculated in calories. Large-scale immigration leads to changes in eating patterns and people consume a greater proportion of beef and, in particular lamb, while milk consumption decreases.

We learnt a huge amount about how the scenarios worked after the idea seminars with stakeholders and researchers (which I will not describe here) and also received many individual opinions. We had a meeting with the small SLU group before the third work meeting were we made the following changes to the scenario laboratory:

- We split the main model into two; Global and Regional and developed both of these models separately
- We renamed the sub-model *Access to resources global "Access to resources land and water global"* and created a similar model for the regional perspective, *"Access to resources land and water regional"*
- We revised the sub-model *Population regional*
- We introduced new dimensions; *Global technological development and distribution*, *Global energy supply* and *Consumptions patterns*
- We sketched out a new sub-model: *Production for consumption*. However, it had to be abandoned since we did not have time to develop it

During the third and final work meeting, we adjusted the conditions in the models and added the final touches to the scenario frameworks from the second work meeting. This is what the scenario laboratory looked like when we were finished (figure 35):

GLOBAL SCENARIOS							
Land-water resouce availability	Power relations	Population 2050	Economic develop-ment	Climate scenarios	Energy supply	Techno-logical develop-ment and distribution	Food consump-tion

REGIONAL SCENARIOS						
Population	Land-water resouces availability	Agricultural policy	Power relations	Economic develop-ment	Food consump-tion	Consump-tion of animal products

Figure 35: Scenario laboratory for Future Agriculture. The laboratory consists of two morphological models; Global scenarios and Regional scenarios. Each one has two sub-models (green boxes).

4.2.3 Comments

The process was very smooth with a core workshop group, expert guests and a small joint SLU-FOI group that worked between the work meetings. This has reinforced my opinion that you can create a flexible knowledge process where you can adapt to the circumstances with the help of morphological analysis.

From a morphological point of view, the challenge was in finding limitations and a good overall structure in the form of a functional scenario laboratory. The meta models were definitely necessary in order to succeed. With their help, we were able to progress quickly between the work meetings, on our own and together with the small group.

We had to spend quite a lot of time and effort on working out what we wanted the scenarios to describe. Our aim was to develop a collection of "neutral" scenarios and to avoid best and worst case scenarios. This proved to be not very easy, but we achieved a certain balance between the scenarios nonetheless. We did this by grinding away at reformulating the focus issue over and over again, and by being careful when we selected conditions for the different scenarios.

We worked alternately on morphological analysis, creating scenario frameworks and descriptions where the development of the text contributed to honing the logic in the scenarios. We benefitted from this a little later in an assignment concerning scenarios for long-term strategic analysis for the Swedish Civil Contingencies Agency.

Future Agriculture gained five good scenarios, which aroused a lot of interest within SLU when they presented them, for example at a seminar on 25 May 2010 (I was there and saw it with my own eyes). The scenario work continued with a seminar for young researchers, where several excellent research ideas were put forward. We also received a follow-up assignment for Future Agriculture – scenarios for Sub-Saharan Africa, where FOI could also offer expertise. The scenario work group has also written an article for AMBIO to be published soon.

4.2.4 Documentation

Stenström, M., Dahlén, L., Jansson, B., Scenarier för Framtidens lantbruk, FOI Memo 3171, 2010

Öhborn et. al., Five Scenarios for 2050 – Conditions for Agriculture and Land Use, SLU, Future Agriculture 2011

Magnusson et. al., A contribution to the discussion on Critical research issues for future sub-Saharan African agriculture, SLU, Future Agriculture 2012

Conclusion

I shall summarise this report by reflecting on the question: How have I changed my way of working with morphological analysis during my years as a morphologist?

The first morphological analysis that I was involved in dealt with developing external environment scenarios for the Swedish Environmental Protection Agency's future study Sweden in the Year 2021[50]. The work took place 1996-97. It was a straightforward process without any fuss that resulted in four different global future projections with sector scenarios connected to them. Perhaps not that special one would think, but the report that the Swedish Environmental Protection Agency issued was the reason why SLU got in contact with us in 2009, hence, over 10 years later. This resulted in the "Scenarier för Framtidens lantbruk" (Scenarios for Future Agriculture) assignment. If I compare both of these studies, I see that there is a core that has not changed and a context in which a great deal has happened during the time I have been a morphologist. The basis is the same: to develop good dimensions and conditions and to select interesting and logically coherent scenario frameworks together with experts. However, we have developed the knowledge process. In the SLU assignment, we actively worked on gradually formulating a clear focus issue, we used meta models and we wrote detailed process reports. We deliberately worked with homework and did quite a lot of back office work. We were also involved in a larger process where we held seminars with stakeholders and researchers who would then generate research ideas based on scenario texts.

A clear change is that I have become a little less orthodox when it comes to the knowledge process. When I started working with morphological analysis, we were very careful to ensure that the group was involved from the beginning. I have softened my attitude towards this and realised the benefits of "semi-finished products". These days, I often start with a suggestion for a model that I have developed either by myself or in a small group, based on the information we have received from the diagnosis and our own investigations. Furthermore, it is quite often possible to recycle ideas from finished models. The advantages of this are that we gain time on the schedule and we save on the experts' precious time. A disadvantage could be that the group does not see the model as its own. However, this can be avoided by underlining that this is only a suggestion, and that everything can be changed during the course of the analysis.

Meta models and process reports are aids that were established at the beginning of the 2000s. At the beginning, we only worked with simple scenario models and the need for giving feedback to the group was not as great at that time. However, as

[50] Swedish Environmental Protection Agency (1997), "Omvärlden år 2021 – fyra globala scenarier", report 4726

we gradually started to build complex scenario laboratories with several models, we realised that meta models are necessary tools in morphological analysis. Being able to illustrate the connection between different models, in hierarchies for example, is a great help in the group's knowledge process. The process reports were established when we realised that morphological analysis can be so knowledge-intensive and bewildering that the participants cannot always keep up. The better a workshop has been, the more confused everyone is. Another reason for writing process reports was to give the participants the conditions for doing homework, something we did not employ from the beginning.

At the beginning, we worked strictly in accordance with Fritz Zwicky's intention, that everything can be input and everything can be output in a morphological model. However, we soon realised the pedagogical benefits of structuring the models, i.e. putting the dimensions in a logical order. What is more, we learnt to manage models that threatened to grow in all directions by creating different modules and hierarchies of models.

The computer software Casper has been developed over the years and has gained some new functions. But that is another story....

When it comes to the process, I have made it more customised (which could be due to the fact that the problems I work with these days are often more complex than the previous scenario-focused studies). Here, for example, the morphological analysis can be combined with other methods such as games and Bayesian networks. There can be several work groups that work with different parts of the problem, and there can be large reference groups that give their points of view regarding the models on several occasions. The least amount of back office work, the better – this was the motto when we started working on morphological analysis. These days, I see back office work (alone, together with FOI colleagues and together with the client) as a good complement to group work.

All in all, computer support, which has become better, and the total process, which has become more flexible and pedagogical over the years, are what have changed the most. However, the core of FOI's morphological analysis, the iterative process and the morphological model still remain.

References

Baddeley, A. (1994), “The Magical Number Seven: Still Magic After all these Years?”, Psychological Review, 101(2)

Bright, J. & Schoeman, M. (eds), A Practical Guide to Technological Forecasting, Prentice Hall

Conklin, E.J. & Weil, W., Wicked Problems: Naming the Pain in Organizations, www.leanconstruction.dk/_root/media/15.pdf 2011-05-18

Coyle, R. G., Yong, Y. C. (1996), “A scenario projection for the South China Sea”, Futures 28(3)

De Waal, A., Ritchey, T. (2007), “Combining morphological analysis and Bayesian networks for strategic decision support”, ORiON, 23(2): 105–121, http://www.orssa.org.za

Friend, J. (2009), “The strategic choice approach”, Rosenhead, J. and Mingers, J. (eds) Rational Analysis for a Problematic World Revisited, 2nd ed., John Wiley&Sons

Gerardin, L. (1973), “Morphological Analysis: A Method for Creativity”, Bright, J. & Schoeman, M. (eds), A Practical Guide to Technological Forecasting, Prentice Hall

Hacking, I. (1999), “The Social Construction of What”, http://www.amazon.com/Social-Construction-What-Ian-Hacking/dp/0674004124#reader_0674004124 18-05-2011

Hogan, C. (2003) “Understanding Facilitation: Theory and principles”, Kogan Page

http://en.wikipedia.org/wiki/Bohm_Dialogue, 18-05-2011

http://en.wikipedia.org/wiki/Wicked_problem, 18-05-2011

Johansen, Iver (2006) “Scenarioklasser i Forsvarsstudie 2007 - en morfologisk analyse av sikkerhetspolitiske utfordringer mot Norge”, FFI report 2006/02664

Kaunitz, Carin and Stenström, Maria, “Morfologisk analys för studien Luftburen förmåga”, Method report, FOI-R--0686--SE, December 2002

Magnusson et. al., A contribution to the discussion on Critical research issues for future sub-Saharan African agriculture, SLU, Future Agriculture 2012

March, James G. (1965), Handbook of organizations, Rand McNally College Publishing Company

Miller, G. A. (1956), “The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information”, Psychological Review, 63

Norris, K. W. (1962), “The Morphological Approach to Engineering Design”, Jones, J. C. & Thornley, D. G. (eds), Conference on Design Methods, London

Pidd, M. (1996), Tools for Thinking, Wiley, page 66

Rhyne, R. (1995), “Field Anomaly Relaxation, The Arts of Usage”, Futures, 27(6)

Ritchey, T. (1991), “Analysis and synthesis. On Scientific Method - Based on a Study by Bernhard Riemann”, Systems Research, 8(4)

Ritchey, T. (1998) “Fritz Zwicky, Morphologie” and Policy Analysis, 16th Conference on Operational Analysis, Brussels

Ritchey, T. (2002), Morphological Analysis – A General Method for Non-Quantified Modelling, FOI, www.foi.se/ma

Ritchey, T. and Stenström, M. (1998), “Samhällsscenarier om mänskliga handlingar som kan påverka djupförvar för radioaktivt avfall i långtidsperspektiv”, FOA-R--98-00919-990--SE

Ritchey, T. (2006), “Problem structuring using computer aided morphological analysis”, Journal of Operational Research Society, 57(7): 792-801

The Rockefeller Foundation and Global Business Network (2010), “Scenarios for the Future of Technology and International Development”, http://www.gbn.com/articles/pdfs/GBN&Rockefeller%20scenarios.technology&development.pdf

Stenström, M. (2004), “Morfologisk analys av SKI:s beredskap”, SKI report 2004:37

Stenström, M., Dahlén, L., Jansson, B., Scenarier för Framtidens lantbruk, FOI Memo 3171, 2010

Stenström, M., Nytt fotbeklädnadssystem för jägare – processbeskrivning och resultat, FOI-memo 791, 03-03-2004

Stenström, M., Ritchey, T. (2004), “Scenarios and Strategies for Extended Producer Responsibility Using Morphological Analysis to evaluate EPR System Strategies in Sweden”, FOI, foi.se/ma

Stenström, M., Westrin, P., Ritchey, T. (2004), “Living with UXO, Using Morphological Analysis for Decision Support in Phasing out Military Firing Ranges. Summary of Report to the Swedish Armed Forces UXO Program”, FOI

Swedish Environmental Protection Agency (1997), “Omvärlden år 2021 – fyra globala scenarier”, report 4726

The Swedish National Encyclopedia Dictionary (Nationalencyklopedins ordbok)

Voros, J. (2009), “Morphological prospection: profiling the shapes of things to come”, Foresight, 11(6): 4-20

www.slu.se/framtidenslantbruk, 18-05-2011

www.slu.se/sv/centrumbildningar-och-projekt/framtidens-lantbruk-/om-framtidens-lantbruk/, 18-05-2011

Öhborn et. al., Five Scenarios for 2050 – Conditions for Agriculture and Land Use, SLU, Future Agriculture 2011

FOI, Swedish Defence Research Agency, is a mainly assignment-funded agency under the Ministry of Defence. The core activities are research, method and technology development, as well as studies conducted in the interests of Swedish defence and the safety and security of society. The organisation employs approximately 1000 personnel of whom about 800 are scientists. This makes FOI Sweden's largest research institute. FOI gives its customers access to leading-edge expertise in a large number of fields such as security policy studies, defence and security related analyses, the assessment of various types of threat, systems for control and management of crises, protection against and management of hazardous substances, IT security and the potential offered by new sensors.

FOI
Swedish Defence Research Agency
SE-164 90 Stockholm

Phone: +46 8 555 030 00
Fax: +46 8 555 031 00

www.foi.se