Morphological Analysis: Big Words, Simple Idea

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ABSTRACT

Today's constantly changing and evolving security environment requires decision makers to consider complex problems where there are many governing factors. Conventional approaches isolate the essential factors and solve the simplified system. However, often a simplified model will break down when the contribution of the inconsequential components becomes significant. Morphological analysis considers all components and works backwards from the solution towards the system's inner parts and linkages.

INTRODUCTION

Morphological analysis was developed by Fritz Zwicky, who was based at the California Institute of Technology. While morphology had been in use before Zwicky's seminal work (Zwicky, 1967) during the 1940s and 50s, he matured the ideas into a rigorous method to address "all relevant interrelations among objects, phenomena and concepts by means of methods which are based on the utmost detachment from prejudice and carefully refrain from all prevaluations" (p. 273). Among his notable body of work he employed his morphological method on topics as diverse as jet engines, astronomical instruments, and law in space (Zwicky, 1947, 1948, 1963).

Morphological analysis breaks down a problem into key dimensions, restructures it, and provides a framework in which people can consider various solutions. The approach systematically explores the range of possible combinations of various attributes or dimensions of the problem. During the exploration, it offers a method of presenting a multidimensional problem in a more simple two-dimensional space to help understanding. Typically, morphological analysis takes place with a small group of subject-matter experts through a series of workshops, and there are many examples of it being used successfully in practice[1]. A definition of morphological analysis that encapsulates its generic status as a problem structuring method is that it is a method for systematically structuring and examining all the possible relationships in a multidimensional, highly complex, usually non-quantifiable problem space. The basic idea is to identify a set of variables and then look at all the possible combinations of these variables […] This exercise [morphological analysis] reduces the chance that events will play out in a way that the analyst has not previously imagined and considered. (Heuer & Pherson, 2011, p. 108)

Initially, morphological analysis was applied in the area of technology within engineering design purposes before being used as a creativity and ideation method (Majaro, 1988). Morphological analysis has been applied to futures and socio-economic fields and in a more generalised approach targeting the broader aspect of "wicked problems" and "messes" (Ackoff, 1974; Coyle, 2004; Funtowitcz & Ravetz, 1994; Godet, 2001; Rhyne, 1995, 2003; Ritchey, 2011; Rittel & Webber, 1973).

[1] See www.swemorph.com for examples

MORPHOLOGICAL ANALYSIS AS A PROCESS

A process for Morphological Analysis is shown in **Figure 1-1: Outline Process for Morphological Analysis.**
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- **Step 1:** First, the problem which is to be solved must be exactly formulated and be encapsulated in the form of a focus question. All of the parameters that might enter into the solution of the given problem must be characterized.[2]
- **Step 2:** The states at which the parameters might exist need to be captured.[3]
- **Step 3:** Then a “morphological table” or multidimensional matrix is constructed which contains all of the solutions of the given problem.
- **Step 4:** All of the solutions are closely analysed and evaluated through a cross-consistency matrix with respect to the purposes to be achieved.
- **Step 5:** The best solutions are selected and executed, provided that the necessary means are available.[4]

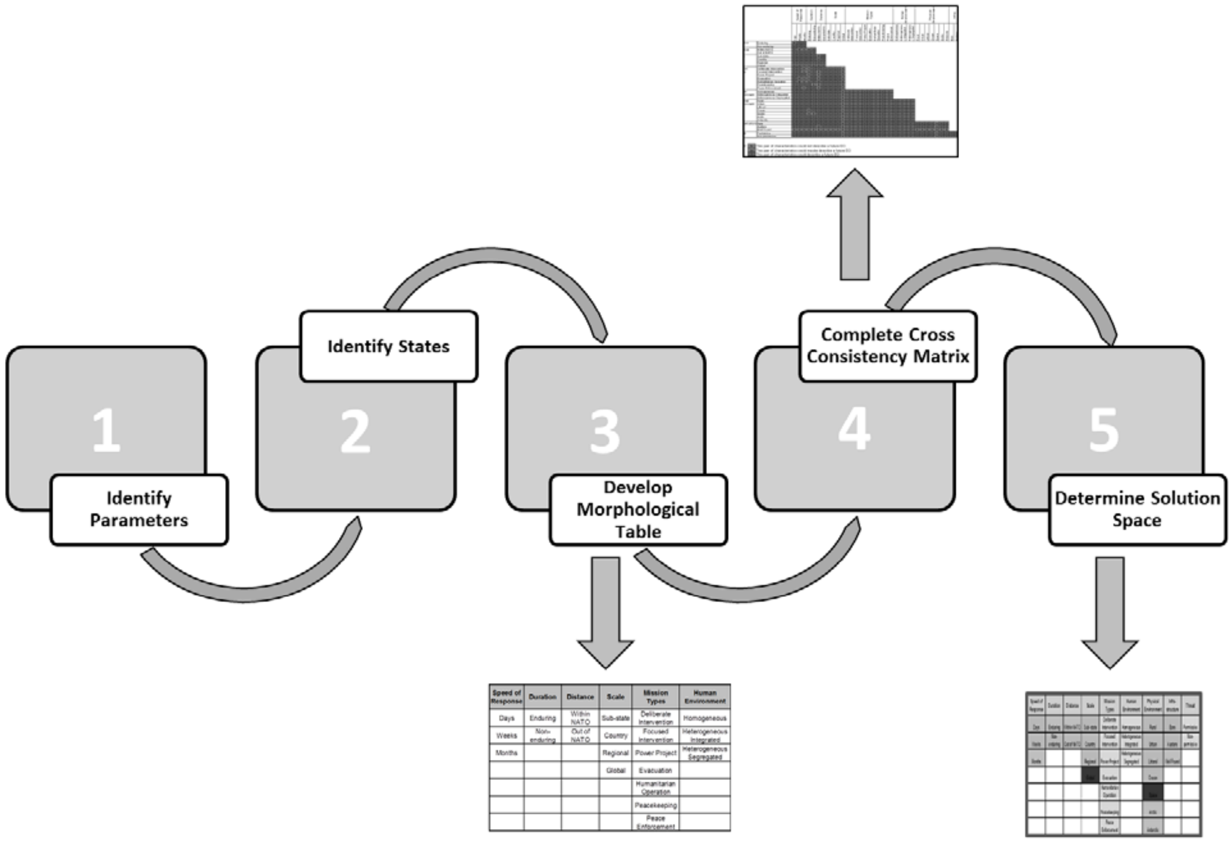

Figure 1-1: Outline Process for Morphological Analysis.

[2] Morphological Analysis sees the employment of the term “Parameters” and “Dimensions” used almost interchangeably. This paper will use Parameters.

[3] These states are referred to as “parameter values”, “scales”, or “states.” This paper will use states.

[4] The number of solutions remaining may require further analysis and a number of techniques including the analytical hierarchy process and classifications trees have been used in conjunction with morphological analysis.

The first output of a morphological analysis, after step 3, is a morphological table; an example is shown in Table 1-1: Morphological Table for AFSC.

. A morphological table illustrates how a problem is broken down into components. The first row of Table 1-1: Morphological Table for AFSC.

shows the parameters of the problem; under each parameter are potential states, which give different value options for each parameter. In this instance, the table is intended to represent a problem space for Alliance Future Surveillance and Control Capability (AFSC).

Table 1-1: Morphological Table for AFSC.

Target Environment	Target Size	Target Movement	Target Range	Signature Vector	Signature Reduction	Domain Clutter	Technology
Air	Microscopic	Static	<100m	Acoustic	Acoustic	None	X
Surface	Tiny	Slow	100m	Electro-optic (Visual)	Electro-optic (Visual)	Some	Y
Emitting	Small	Subsonic (<M1)	1km	Infra-red / Thermal	Infra-red / Thermal	Lots	Z
Space	Medium	Supersonic (M5)	10km	Electro-Magnetic	Electro-Magnetic		…
Cyber	Large	Hypersonic (M25)	200km	Other (e.g. Magnetic, UV, chemical)	Other		…
Other (e.g subsurface)	Huge		2,000km				…
			40,000km				…
			40,000km+				…

Typically, morphological analysis uses a workshop format to derive parameters and states from a group of experts on the topic under scrutiny. It is desirable that parameters be orthogonal in the sense that it should not be possible to define one parameter from a combination of two or more other parameters. The set of

states for each parameter should be exhaustive, so that for the purposes of the topic, all possible values of a parameter should be captured. Such "stretching" of the states conforms to Zwicky's idea that morphological analysis should allow for "totality research".
Formulating a novel problem takes time. Consequently, it works best when the morphological table can be limited to a reasonable number of parameters and states. When a workshop format is used, it is typical that the constraint is "7 × 7 × 7": seven experts, seven parameters, each with no more than seven states. For example, the table in Table 1-1: Morphological Table for AFSC.

generates over 42,000 potential scenes.

CROSS-CONSISTENCY ASSESSMENT

Step 4 in the morphological analysis process is to eliminate non-valid combinations of states though the principle of contradiction and reduction. Using a cross-consistency matrix, each state is compared in a pairwise fashion with all the other states, see Table 1.2. In the comparison, the idea is to reduce the number of valid configurations by identifying those that are inconsistent with each other. By eliminating inconsistent pairs, the number of combinations to consider reduces considerably. It is not uncommon to reduce the number of combinations by 90% or more (Ritchey, 2011).

Table 1-2 Cross-consistency assessment matrix

Target Environment	Target Size	Target Movement	Target Range	Signature Vector	Signature Reduction	Domain Clutter	Technology
Air	Microscopic	Static	<100m	Acoustic	Acoustic	None	X
Surface	Tiny	Slow	100m	Electro-optic (Visual)	Electro-optic (Visual)	Some	Y
Emitting	Small	Subsonic (<M1)	1km	Infra-red / Thermal	Infra-red / Thermal	Lots	Z
Space	Medium	Supersonic (M5)	10km	Electro-Magnetic	Electro-Magnetic		...
Cyber	Large	Hypersonic (M25)	200km	Other (e.g. Magnetic, UV, chemical)	Other		...
Other (e.g subsurface)	Huge		2,000km				...
			40,000km				...
			40,000km+				...

Sometimes, it is necessary to classify an inconsistency. Three classifications of inconsistency are used.

- **Logical Contradictions**: A logical contradiction between two or more statements.
- **Empirical Inconsistencies**: A practical incompatibility or discrepancy between two or more conditions or statements about the observed world.

– **Normative Constraints**: An incompatibility or discrepancy between two or more conditions based on social norms, ethics, and standards.

SOLUTION SPACE

The final step in the morphological analysis process is to discuss the remaining valid combinations as potential solutions to the problem. A solution is a scene that is consistent across all of the parameters. Table 1.3 highlights a potential example of a solution space for AFSC.

Table 1-3 Solution space matrix for AFSC
Codes: green=possible; yellow= might be possible; red=impossible

Target Environment	Target Size	Target Movement	Target Range	Signature Vector	Signature Reduction	Domain Clutter	Technology
Air	Microscopic	Static	<100m	Acoustic	Acoustic	None	X
Surface	Tiny	Slow	100m	Electro-optic (Visual)	Electro-optic (Visual)	Some	Y
Emitting	Small	Subsonic (<M1)	1km	Infra-red / Thermal	Infra-red / Thermal	Lots	Z
Space	Medium	Supersonic (M5)	10km	Electro-Magnetic	Electro-Magnetic		...
Cyber	Large	Hypersonic (M25)	200km	Other (e.g. Magnetic, UV, chemical)	Other		...
Other (e.g subsurface)	Huge		2,000km				...
			40,000km				...
			40,000km+				...

UTILITY OF MORPHOLOGICAL ANALYSIS FOR NATO

NATO uses concepts as a mechanism to solve difficult transformational problems. These problems often represent an unfulfilled military capability requirement or the need to improve an existing capability via innovation. NATO work on transformational problems is supported by a number of analytical and experimentation techniques. These include partial problem formulation, iteration, and the use of formal events managed under experimentation best practice to verify and validate ideas. The application of these techniques has proven value within NATO. Work on transformational problems has identified a number of frequently occurring problem characteristics.

– First, the importance of seeking a range of disparate views on a topic in order to account for complexity and broad range of actors involved; and the difficultly to manage or incorporate these disparate and often conflicting views into a coherent whole.
– Second, contemporary military problems rarely have obvious solutions, so it is often not clear when their work should conclude.
– Third, that it is difficult to demonstrate objectively that a proposed solution is right or wrong;

solutions are increasingly context dependent.

Morphological analysis can be applied to alleviate these problem characteristics. It is a method that collates a range of disparate views and brings them into a coherent whole. It encourages a comprehensive search for non-obvious solutions, forcing participants to consider innovative solutions as well as challenging their assumptions for deselecting novel solutions. And it facilitates “better or worse” discussions among decision makers, enabling results to be placed in context and thereby allowing decision makers to understand the implications of assumptions made and actions taken.

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