

Getting Off to a Good Start: Improving Definitions Using Morphological Analysis

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ABSTRACT

NATO aspires to be the final arbitrating body in developing agreed definitions between its member nations. The reality is that many NATO definitions in use are what can be agreed upon between the disparate parties, rather than being rigorously derived. Frequently, they are ambiguous and vague and consequently they offer little to direct or inform analysis work. An ambiguous and vague definition can be better than nothing, but NATO should aspire to improve the manner in which definitions are derived, since they form the fundamental building-blocks on which conceptual and capability efforts are built.

The paper dwells on a recent case study of a requirements analysis undertaken for NATO Expeditionary Operations. Specifically, the presentation covers the problems of the definition of Expeditionary Operations in use within NATO and the methods employed by ACT analysts to develop an improved definition.

INTRODUCTION

NATO aspires to be the final arbitrating body in developing agreed definitions between its member nations. The reality is that many of the definitions in use within NATO are what could be agreed upon between various parties holding different views, rather than having being rigorously derived. Frequently, NATO definitions are ambiguous and vague and offer little to direct or inform supporting work. In some cases, an agreeable but ambiguous definition may be better than nothing, but NATO should aspire to improve the rigour with which definitions are derived, since they form the fundamental building-blocks on which conceptual and capability efforts are built.

This paper presents an analysis method employed by a Specialist Team on Characteristics of Operations for Future Expeditionary Forces (SAS-075). This paper discusses the method selected, General Morphological Analysis, its benefits and limitations, and how the team overcame these limitations by combining it in a multi-method approach.

BACKGROUND

Rittel & Webber wrote about two types of problems: “Tame” and “Wicked”¹. Tame problems were well defined, easily quantifiable, and had definite solutions that could be measured and compared to similar problems that had been solved successfully before. Conversely, Wicked problems were unique, hard to define

¹ Rittel & Webber, “Dilemmas in a General Theory of Planning”, 1973.

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or bound, they had no stopping rules, no obvious solutions nor any immediate test of the quality of the solution.

There are different strategies for approaching Wicked problems²:

- Authoritative (a small group is formed to tackle the problem);
- Competitive (the problem is opened up to competing groups) and;
- Collaborative (a wide range of views taken into account).

METHOD

General Morphological Analysis

Developed by Zwicky, General Morphological Analysis breaks down a problem into its key dimensions, restructures it and provides a framework in which people can consider various solutions. It offers a method of presenting a multi-dimensional problem in a two-dimensional space in order to ease understanding. General Morphological Analysis may be considered to be an authoritative approach; since it brings together a small group of experts.

The first step in General Morphological Analysis is to create a Morphological Table; an example of a Morphological Table is shown in Figure 1. This table was developed by the SAS-075 team to address the specific question:

“What is NATO’s definition of an Expeditionary Operation?”

Figure 1 shows how the Morphological table is used to break down a problem into its key components. The first row of Figure 1 (in grey) shows the dimensions³ of the problem; under each dimension are scalars⁴, which give different value options for each dimension. In this instance, the table is intended to represent the whole intellectual space, of which the solution (the answer to the question above) is some portion that describes the sub-set of operations that are considered to be Expeditionary.

² Roberts, N.C. “Wicked Problems and Network Approaches to Resolution,,” The International Public Management Review., Vol. 1, 2000.

³ Called ‘parameters’ in General Morphological Analysis terminology.

⁴ Called ‘parameter value range’ in General Morphological Analysis terminology.

Speed of Response	Duration	Distance	Scale	Mission Types	Human Environment	Physical Environment	Infra-structure	Threat
Days	Enduring	Within NATO	Sub-state	Deliberate Intervention	Homogeneous	Rural	Bare	Permissive
Weeks	Non-enduring	Out of NATO	Country	Focused Intervention	Heterogeneous Integrated	Urban	Austere	Non-permissive
Months			Regional	Power Project	Heterogeneous Segregated	Littoral	Well Found	
			Global	Evacuation		Ocean		
				Humanitarian Operation		Space		
				Peacekeeping		Arctic		
				Peace Enforcement		Antarctic		

Figure 1: NATO Operations Morphological Table

The General Morphological Analysis typically 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 practice⁵.

Limitations of General Morphological Analysis

General Morphological Analysis is a very useful method for problem structuring and solution consideration; however, it works best when the Morphological table can be limited to fewer than seven dimensions. NATO's problems are often very complex and in this instance a larger table was needed to describe the problem fully. Using a classic Morphological Analysis approach with a large table, the data set quickly becomes unmanageable for a group to consider, for example, the table in Figure 1, the data set consists of 42,336 potential operations⁶.

NATO also requires consultation with at least twenty-eight nations, plus academia and other agencies, spread out over a wide geographic area. Gathering everyone's opinions can be impractical for a single or even a series of small workshops. A way of remotely capturing opinions on an individual basis plus a way of consolidating those opinions is highly desirable, as more experts can be reached, as well as reducing costs and travel time for the analysts. General Morphological Analysis does not offer this.

Data Capture

A tool has been created to capture opinions based on any Morphological Table and this creates a resulting data set for analysis. This tool can be sent via email to as many people as desired, or it can be used by the analyst to capture opinions from individuals or small groups through interactive discussions.

⁵ See www.swemorph.com for examples.

⁶ The number of potential combinations can be calculated by multiplying the number of scalars in each dimension e.g. Speed of Response (3) x Duration (2) x Distance (3) x Scale (4) x Mission (7) x Human Environment (3) x Physical Environment (7) x Infrastructure (3) x Threat (2) = 3 x 2 x 3 x 4 x 7 x 3 x 7 x 3 x 2 = 42336.

There are advantages and disadvantages to both methods. Sending it to individuals allows a large group to be targeted with minimal effort from an analyst, but with the usual issues with response rate. Employing the tool to collect data in individual or small group discussions takes more analyst time; however the confidence in the quality of the data increases, for example, workshop participants can be encouraged to consider about each answer carefully, with the discussions translated by analysts who are experts in the tool.

The tool currently uses MS Excel software and Visual Basic for Applications. Excel was used because it provided all of the necessary functionality and a graphical user interface, as well as being widely understood and accessible by other users, which is important for remote data collection.

The tool is in two parts. The first requires the respondent to consider each scalar individually and remove any irrelevant scalars from the list. The tool then does a pair-wise comparison between all remaining scalars and asks the expert to identify valid and erroneous combinations.

The tool is interactive and dynamic – it takes user input and then dynamically changes the questions depending on the earlier answers. This reduces quickly the number of questions a participant has to answer, and therefore large Morphological tables can be examined. For example, using the tool to examine the table in Figure 1 results in over 500 potential questions, but this is quickly reduced and a typical time to respond using the data capture tool is around 30 minutes.

The tool displays the results of a single response in a Cross-Consistency Matrix. Currently the tool requires responses in the form of “Yes”, “Maybe” or “No” identifying the validity of each pair of scalars, but the responses can be in any form defined by the analyst.

An example of a Cross-Consistency Matrix produced by the tool is shown in Figure 2.

		Speed of Response			Duration		Distance		Scale			
		Days	Weeks	Months	Enduring	Non-enduring	Within NATO	Out of NATO	Sub-state	Country	Regional	Global
Duration	Enduring	M	Y	Y								
	Non-enduring	Y	Y	Y								
Distance	Within NATO	Y	M	N	M	Y						
	Out of NATO	Y	Y	Y	Y	Y						
Scale	Sub-state	Y	Y	Y	Y	Y	N	Y				
	Country	Y	Y	Y	Y	Y	M	Y				
	Regional	Y	Y	Y	Y	Y	Y	Y				
	Global	N	N	N	N	N	N	N				
Mission Types	Deliberate Intervention	Y	Y	M	N	Y	Y	Y	Y	Y	Y	N
	Focused Intervention	Y	Y	N	N	Y	N	Y	Y	Y	Y	N
	Power Project	Y	Y	Y	N	Y	N	Y	Y	Y	Y	N
	Evacuation	Y	M	N	N	Y	N	Y	Y	Y	Y	N
	Humanitarian Operation	Y	M	N	N	Y	M	Y	Y	Y	Y	N
	Peacekeeping	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N
	Peace Enforcement	Y	Y	N	Y	Y	N	Y	Y	Y	Y	N

Figure 2: Cross Consistency Matrix with example data

Data from each individual's Cross-Consistency Matrix are transferred into an analysis tool that combines the results and extracts a full list of valid combinations of scalars, or in the example above, valid NATO Expeditionary Operations.

The next step in the General Morphological Analysis process would be to eliminate non-valid combinations of scalars. By eliminating these, the number of combinations to consider reduces considerably. Non-valid combinations can be classified as:

Logical Contradictions:

- A logical contradiction between two or more statements;
- e.g. An operation in the Antarctic that is within NATO.

Empirical Inconsistencies:

- A practical incompatibility or discrepancy between two or more conditions or statements about the observed world;
- e.g. An urban operation at Global scale – this is not impossible, just extremely unlikely.

Normative Constraints:

- An incompatibility or discrepancy between two or more conditions based on social norms, ethics and standards;
- e.g. A non-permissive humanitarian operation.

The final step in General Morphological Analysis is to discuss remaining valid combinations as potential solutions to the problem. In the example given in Figure 1, a valid combination would be a single scalar selected from each of the nine dimensions that together to describe a potential Expeditionary Operation.

Data can be consolidated by listing all potential combinations and counting the number of times each combination was identified as valid by the respondents. Depending on the number of respondents, a minimum number of votes for each combination will need to be determined by the analyst; however this can be done by looking intelligently at the data and conducting sensitivity analysis to ensure the chosen cut off point does not skew the results.

Classification Trees

The next step in the process is to employ Classification Trees to analyse the consolidated data. In this case SPSS software⁷ was used to process data; however other appropriate statistical packages could be used.

A Classification Tree is a data mining technique used to predict the membership of a dependant variable using predictor variables. The dependant variable is the response to the question “Is this combination of scalars a valid NATO Expeditionary Operation?” answers to which were captured in the data capture tool. The predictor variables are the dimensions and scalars in the Morphological Table (Figure 1). For any combination of scalars, the Classification Trees predict whether the combination is likely to be valid, based on the collective responses. It shows the degree of consensus within the data set. The data set can also be broken down by type of respondent, for example, civilian versus military respondents.

A Classification Tree determines the relative importance of dimensions and scalars when predicting membership of the dependent variable. In the example, Figure 3, the first level of the tree shows that 7,510 out of 42,336 operations were determined by respondents to be valid Expeditionary Operations.

Figure 3 also shows that respondents considered that a majority of valid Expeditionary Operations were conducted outside of NATO’s boundaries; this was the most significant predictor value. The next most significant predictor was operation scale; with an overwhelming majority of Expeditionary Operations considered to be smaller than Global.

⁷ See www.spss.com for more details

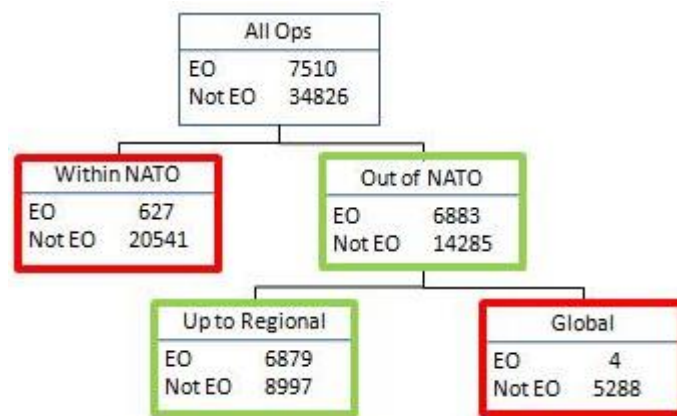


Figure 3: Example of a Classification tree down to 3 levels

Figure 4 shows the Classification Tree data in the form of a scale Venn diagram. The outer circle represents the whole data set, with the Red and Blue areas representing all valid combinations, distinguished by the predictor variable Out of or Within NATO.

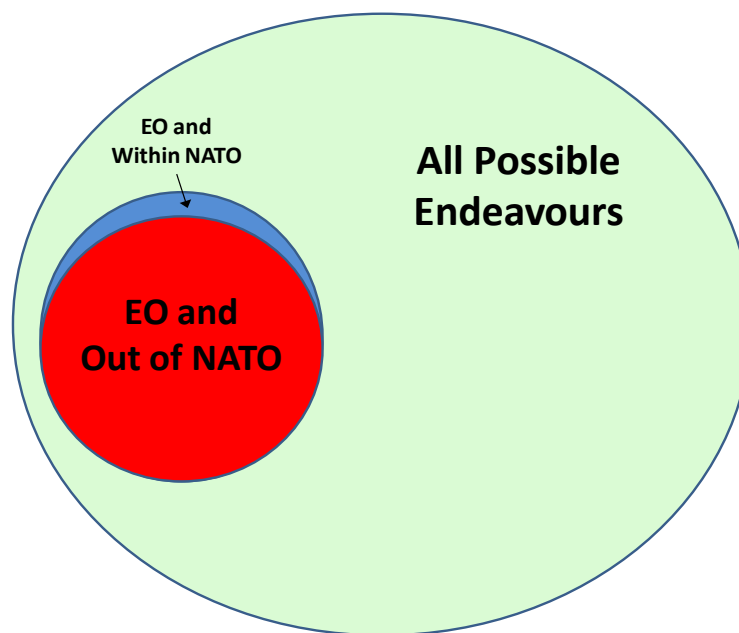


Figure 4: Venn diagram resulting from classification tree analysis

Predictive Rule Sets

By analysing the classification tree, the analyst can build rule sets that model different problem definitions or different solutions to the original question. Figure 5 shows that four rules are necessary to describe a large proportion of Expeditionary Operations.

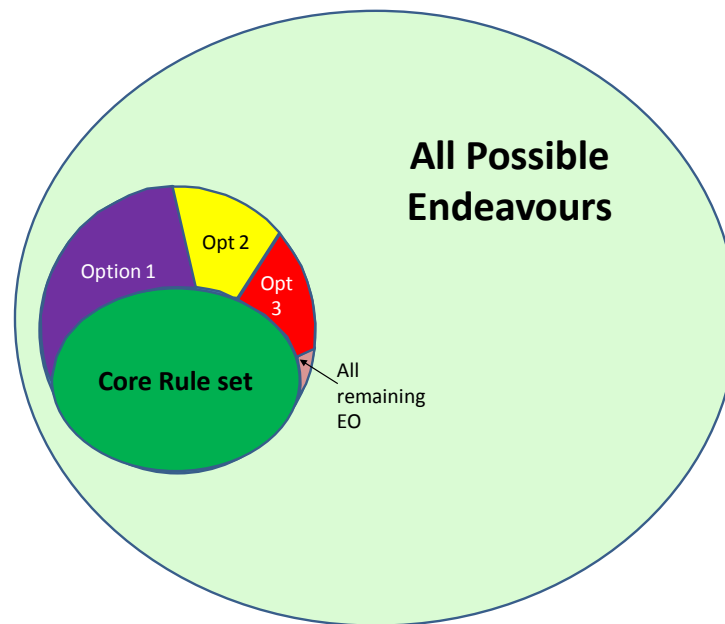


Figure 5: Scale Venn diagram showing Expeditionary Operations Rule Sets

Rule Set Accuracy

The rules depicted in Figure 5 can be measured for accuracy. This can be summarised using a confusion matrix, shown in Figure 6. This can show the number of correct predictions made by the rules, and the number of Type 1 & 2 errors (False positives & negatives).

		Is the mission actually?	
		EO	Not EO
Does the model predict?	EO	A (Correct predictions)	B (False Positive)
	Not EO	C (False Negative)	D (Correct predictions)

Figure 6: Confusion Matrix

A number of metrics can be calculated from the confusion matrix:

- Sensitivity or Recall: $A/(A+B)$: A measure of the mis-classifications i.e. how many combinations are classified as valid by the rule set that are actually not valid;
- Precision: $A / (A+C)$: This is the percentage of all valid combinations that are covered by the rule; and
- Model Accuracy: $(A+D) / (A+B+C+D)$: An overall measure of model accuracy.

Comparison of Opinions

Individual or group opinions can be compared to each other using the accuracy measures. In Figure 7, existing definitions for ‘Expeditionary’ are compared against the rules generated through the data capture process using measures of their precision (coverage of the Expeditionary space) and sensitivity (ability to identify correctly something as Expeditionary). Better definitions score higher on both axes; however different strategies may trade one off against another depending on whether it is more important to cover all opinions (“the NATO way”) or to have very few incorrect predictions. In addition to collating individual or group opinions, the method allowed for key documents to be included in the visualisation – with a survey completed ‘on behalf’ of the document. The views solicited via the Morphological Analysis are in Green, Key NATO documents are in Blue, and a USA Marine Corps document in Yellow.

Figure 7 shows that the points connected by the Red line are on a boundary; points on the line are the best options to select for different prioritisations of Sensitivity and Precision, other points (the Concept Vision and Framework and the EO Vision for Shaping Future Capabilities) are dominated. We can improve the sensitivity of a definition from the current definition by selecting any of the generated options or the US Marine Corps definition, but Precision is lost. Overall, a small loss of Precision may be considered a reasonable trade for the large increase in Sensitivity.

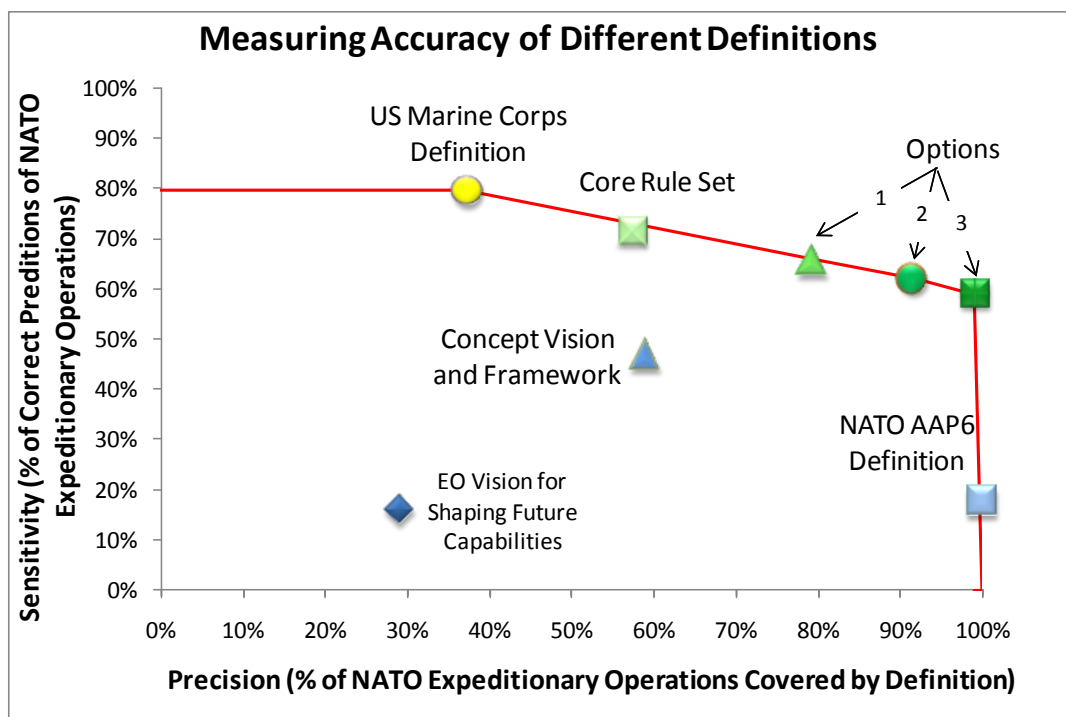


Figure 7: Comparison of different Existing Definitions against the New Rule Set

SUMMARY

Figure 8 summarises the basic analytical process, and shows how the process has been extended from the classic General Morphological Analysis approach. Note the cyclical nature of creating a rule set, testing for accuracy and modifying the rule set to improve accuracy as necessary.

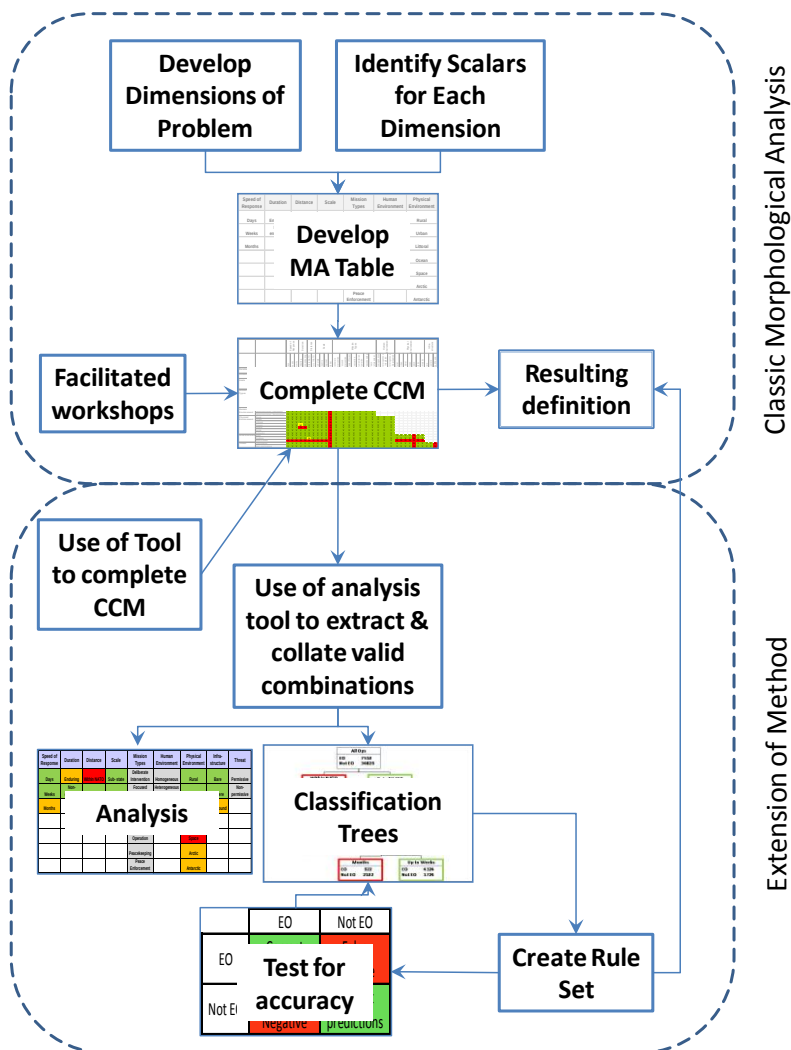


Figure 8: Summary of Analytical Process

SAS-075 has developed a generic method that enables disparate views on a complex problem to be elicited and consolidated in an analytically rigorous manner. Although targeted at a specific problem, this method has the potential for wide utility within NATO and national Capability Development domains.