Using Morphological Analysis for evaluating Preparedness for Accidents Involving Hazardous Materials

Adapted from an article presented at the 4th International Conference for Local Authorities, Shanghai, November, 2002.

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Introduction

Fortunately, accidents involving hazardous materials, e.g. dangerous chemical substances, are relatively rare in Scandinavia. When they do occur, however, the consequences – both for life and the environment – can be serious. Municipal and county rescue services must therefore maintain adequate preparedness for those types of accidents, which can occur within their geographical areas of responsibility.

However, the fact that such accidents are rare makes it difficult for rescue services to gain sufficient experience and routine, as is the case with fire fighting or traffic accidents. One way to increase preparedness is through theoretical evaluations and with the help of scenarios, in order to identify potential deficiencies and to see where improvements can best be made.

For this purpose, FOI – the Swedish Defence Research Agency in Stockholm – was commissioned by the Swedish National Rescue Services Agency to develop a computer-based instrument for evaluating Swedish Rescue Services' preparedness for accidents involving hazardous materials, and also for terrorist actions involving the intentional release of chemical agents. The evaluation instrument was developed using the method of morphological analysis, supported by MA/*Casper* (Computer Aided Scenario and Problem Evaluation Routine), both of which will be described below. An expert group consisting of nine experienced fire marshals and fire engineers from different parts of Sweden, together with the authors, developed the prototype during 1999 and 2000.

The MA/Casper process

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

MA was developed in order to facilitate group work and co-operation both between different scientific disciplines and between actors in different sectors and organisational levels in society. The end result of such a morphological analysis is a morphological field which describes the total problem complex, and which can be used as an "if-then" laboratory in order to test various inputs against possible outputs. Because of the complexity of the process, and the many thousands of potential configurations mapped out in even relatively small morphological fields, MA is difficult to employ without computer support. For this reason, FOA has developed *Casper*: Computer Aided Scenario and Problem Evaluation Routine[1], which supports the entire MA-process.

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

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

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

Step 1: Identify the dimensions, parameters or variables, which best define the essential nature of the problem complex or scenario. This is no trivial task and should be given ample time, depending on the nature of the problem. One should work with no more than 6-7 variables at a time.

Step 2: For each variable, define a range of relevant, discrete *values or conditions*, which the variable can express.

The variable and variable-condition matrix is the morphological field -- an n-dimensional co-ordinate system that implicitly contains an outcome space for the problem complex thus defined.

Synthesis phase: Link variables and synthesise an outcome space.

Step 3: Assess the internal consistency of all pairs of variable conditions, weeding out all inconsistent or contradictory pairs (CASPER provides a systematic procedure for this step). It is usually at this point that one begins to understand what the variables and variable conditions actually represent, and that they are often poorly defined -- i.e. "we don't know what we are talking about yet". Steps 1 and 2 can now be reviewed and one can begin to iterate between steps 1, 2 and 3 until step 3 begins to work smoothly.

Step 4: Synthesise an internally consistent outcome space. CASPER does this by running through all of the possible formal solutions in the morphological field (there can be many thousands) and "reducing" the field by throwing out all outcomes containing internal contradictions. This leaves a "real solution space".

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

At this point, one has created a non-quantified "if-then" laboratory within which one can define drivers, assume certain conditions, and find the range of associated solutions.

The Instrument for use by the Rescue Services

The evaluation instrument for the Rescue Services is made up of two inter-linked matrices: a general preparedness **Resource** matrix and a scenario specific **Response** matrix.

Resource matrix

A rescue service's preparedness is described with the aid of a Resource matrix. This matrix is general, in that all possible rescue services – from part-time organisations in small municipalities to large metropolitan organisations – can be described within it. The resources are described by five parameters (the first five columns in the matrix below). These are:

- **Planning/Plans**: the level of preparedness planning for chemical accidentsmaterials.
- **Education and training**: the general level of training, exercises, and education among rescue service personnel.
- **Personnel**: the number of personnel available, in place, within the critical time period for a given accident
- **Equipment**: the quality and quantity of relevant, available equipment, in place.
- **Leadership**: the command level, which can be activated within the critical time period for the accident.

The alternative values or conditions, which each parameter can be given, are listed below it.

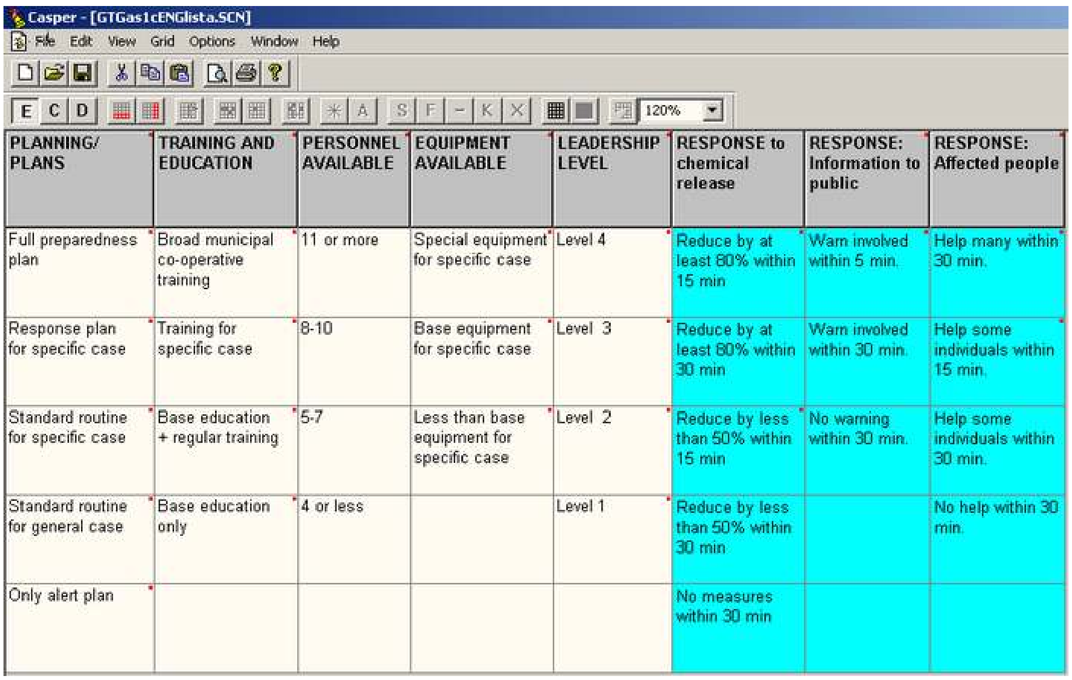
Response matrix

A Response matrix (the three rightmost columns in the matrix below) describes possible responses that a rescue service can make (depending on its resources) within a set of critical time periods defined by a **specific scenario**. It is important to keep in mind that it is **preparedness** that we are assessing with this instrument, not what *might* be the actual outcome due to chance or outside influences.

All Response matrixes have the same general parameters:

- Responses associated with managing/controlling the release itself
- Responses concerning information dissemination to the public, and especially those in danger due to the release
- Responses associated with evacuation or rescuing people threatened or injured by the effects of the release

The exact formulation of the parameters, their order of priority and the ”levels of response” expressed within them, are defined by way of specific scenarios. In the figures below, a scenario involving the release of a poisonous, pressurised gas, e.g. ammonia or chlorine, defines the response matrix. Any number of scenarios can be developed, thus redefining the parameters and values of the response matrix, in order to test preparedness for different types of accidents, or even other types of societal disruptions or disasters.



PLANNING/ PLANS	TRAINING AND EDUCATION	PERSONNEL AVAILABLE	EQUIPMENT AVAILABLE	LEADERSHIP LEVEL	RESPONSE to chemical release	RESPONSE: Information to public	RESPONSE: Affected people
Full preparedness plan	Broad municipal co-operative training	11 or more	Special equipment for specific case	Level 4	Reduce by at least 80% within 15 min	Warn involved within 5 min.	Help many within 30 min.
Response plan for specific case	Training for specific case	8-10	Base equipment for specific case	Level 3	Reduce by at least 80% within 30 min	Warn involved within 30 min.	Help some individuals within 15 min.
Standard routine for specific case	Base education + regular training	5-7	Less than base equipment for specific case	Level 2	Reduce by less than 50% within 15 min	No warning within 30 min.	Help some individuals within 30 min.
Standard routine for general case	Base education only	4 or less		Level 1	Reduce by less than 50% within 30 min		No help within 30 min.
Only alert plan					No measures within 30 min		

Figure 1. Evaluation matrix with Resources(red) as input, Response(blue) as output.

Cross-consistency assessments

The main drawback with most evaluations of this kind, involving numbers of non-quantifiable, semi-dependent variables, is that the internal relationships between the variables are not assessed. Morphological analysis allows for such an internal assessment.

Each ”value” under each of the Resource parameters and Response parameters is compared, in a pair-wise manner, to all of the other values, much like a cross-impact matrix. In this case, however, rather than looking for causal relationships, we look for mutual consistency. With each pair-wise relation, a judgement is made as to whether the pair can co-exist, i.e. whether it is a consistent or contradictory relationship.

Below is the cross-consistency matrix for a poisonous, pressurised gas scenario.

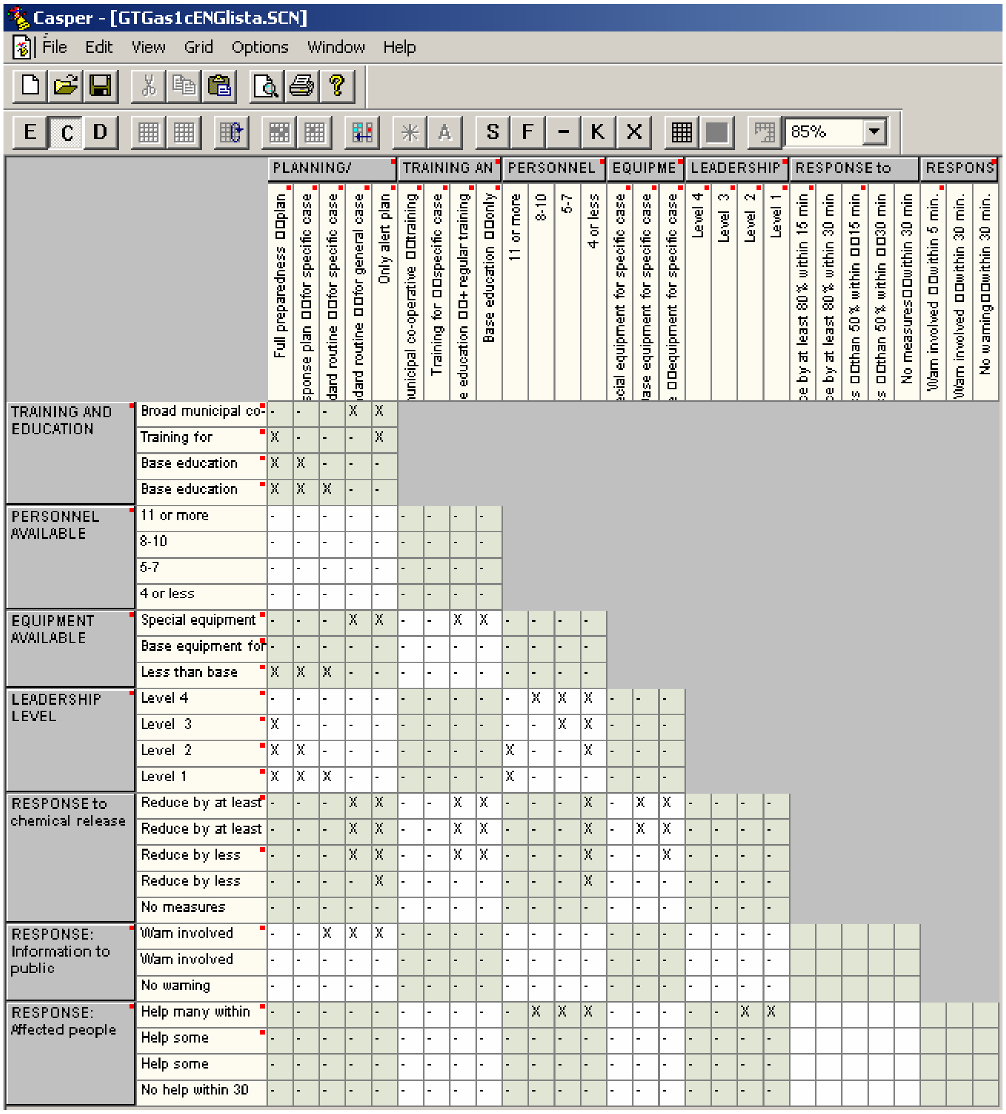


Figure 2. Cross-consistency matrix for scenario involving release of a poisonous pressurised gas. "X" marks incompatible relationships.

How to use the instrument

Step 1: Choose type-scenario

The instrument includes a set of "type-scenarios" describing accidents or intentional actions incidents involving chemical substances. These include, *inter alia*, accidents involving poisonous or otherwise dangerous condensed gases, inflammable liquids, dangerous solid materials (e.g. explosives), and a terrorist action involving the release of the nerve gas sarin. Rescues services choose those type-situations, which are relevant for their municipalities. The scenarios do not indicate *where* the accident or incident takes place in a municipality. Each rescue service should choose one or more geo-demographic locations within the municipality, in order to test response times and potential consequences.

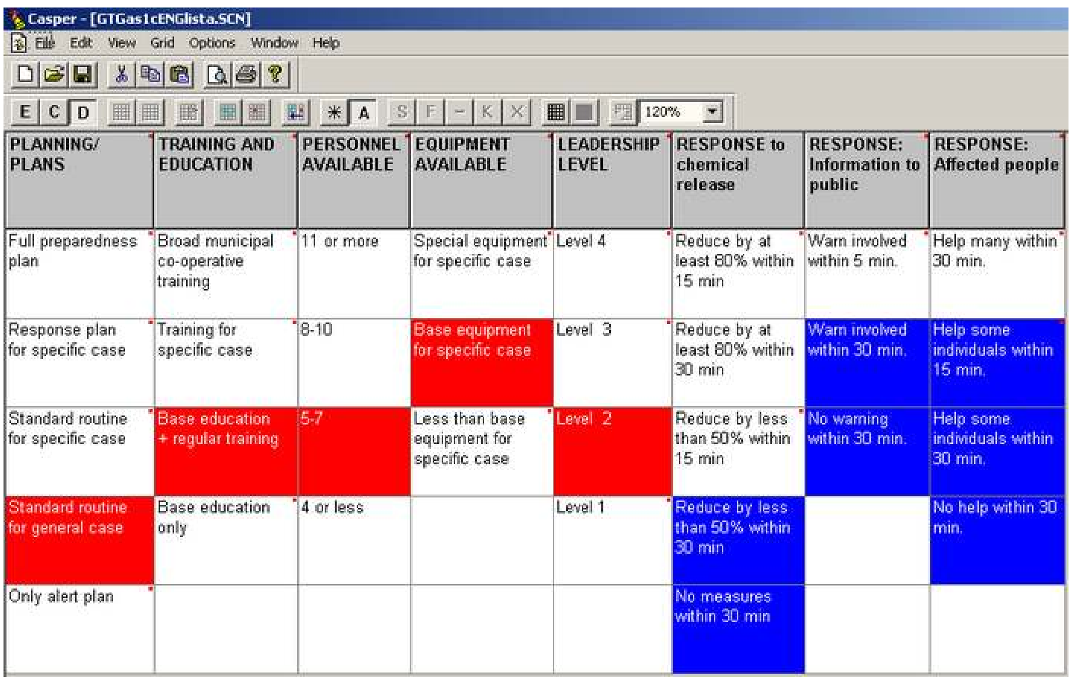
Step 2: Utilise the Instrument

After a scenario is chosen, the evaluation program containing that scenario is opened. There are two ways to apply the evaluation matrix. The first way is to see what level of response is attainable for the resources available to the rescue mission in question. Here we use the *Resource matrix* as an ”input”, and *Response level* as ”output”.

One proceeds as follows:

With a mouse-click, one value under each of the Resource parameters is chosen, which corresponds to the resources available at the given rescue service organisation under consideration and for the chosen scenario. (Each ”value” or cell has a corresponding text area or ”scratch pad” which carefully defines what each resource value means.) The result will be displayed on the Response Matrix, i.e. to what extent a rescue service with the given resources can handle the scenario at hand (as in Figure 1, above). From this configuration, one can test other specific resource values, in order to see which resource increases will lead to the quickest improvements in preparedness, i.e. giving a better result in the Response matrix.

The second way to apply the instrument is to see what resources would be required in order to realise a desired level of response in the Response Matrix. Here we use the Response Matrix as input, and the Resource Matrix as output (Figure 3, below). This mode of use is more suited for the task of municipal planning, e.g. in dialogue with political decision-makers.



PLANNING/ PLANS	TRAINING AND EDUCATION	PERSONNEL AVAILABLE	EQUIPMENT AVAILABLE	LEADERSHIP LEVEL	RESPONSE to chemical release	RESPONSE: Information to public	RESPONSE: Affected people
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Figure 3. Evaluation matrix with Response (red) as input, Resources(blue) as output.

Step 3: Assess consequences

On the basis of the result given in the response matrix for the particular scenario chosen, combined with the chosen geographical location of the accident, assess the possible consequences of such an accident and response. It is important to choose a relevant location and time of day etc. in order to test resources, and to provide a suitable challenge for the rescue organisation. Worst-case locations and times should be examined, as well as locations where accidents would be most expected to occur.

Conclusions

The evaluation instrument proposed is not an ”automatic assessment tool” that defines preparedness with millimetre precision. Instead, it is the motor in an evaluation process based on expert judgement. The main advantage of this method is that the process becomes transparent, since the instrument demands clarity, traceability and consensus concerning the concepts involved. In order to realise these benefits, the evaluation process should be led by an experienced facilitator who understands both the area of application and the method of morphological analysis. It should also be noted that the instrument is not used in order to “give a score” or otherwise rate different rescue service organisations. Its purpose is to facilitate structured, constructive discussions concerning how preparedness can be improved in a municipal rescue service.

We have tested the instrument at six rescue services in different parts of Sweden. The tests have been well received and the test groups have enthusiastically discussed their own preparedness, including what can most easily be improved in order to attain better results. Contrary to our original concerns that rescue services might tend to exaggerate their own resource levels – in order to attain better "results" on the response matrix – we found that they were, in fact, very careful to avoid doing this. We thus find the instrument a valuable resource for preparedness assessments *within* a rescue service, allowing for structured discussions and furnishing a method to help identify the effective means for improvements.

There are also possibilities of using the instrument as a municipal planning tool, in support of a dialogue between rescue services and political decision-makers. One of the principal issues in this context is the boundary between a rescue service’s operational contribution to a secure community, and the strategic responsibilities of community planners.

Further reading:

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Zwicky, F. (1969). *Discovery, Invention, Research - Through the Morphological Approach*, Toronto: The Macmillan Company.