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Fuzzy logic model for sNEBA

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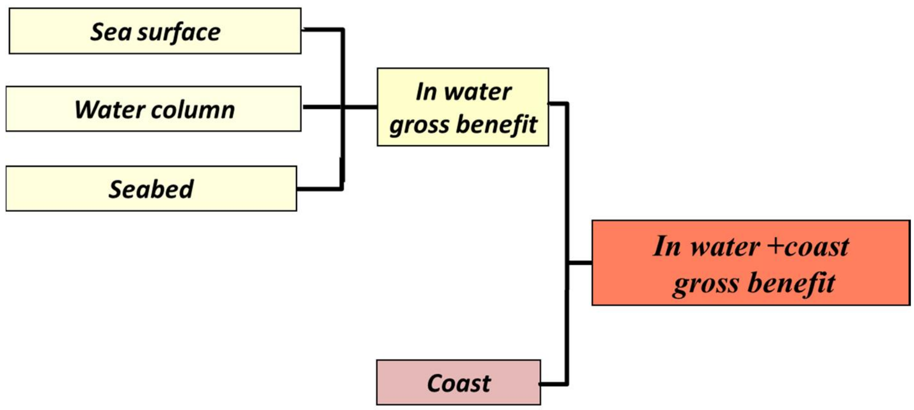
WP5: Strategic Net Environmental Benefit Analysis (sNEBA)



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Executive Summary

Within work package 5, one goal of sNEBA is to find a most proper oil spill combat technique which minimises the environmental impact of both oil spill and oil spill response techniques. This evaluation can be completed for all marine spatial compartments (sea surface, water column, seabed, and coast) by assessing the environmental pros and cons of the different oil spill response techniques relying on knowledge matrixes reported in deliverable D5.5 (Matrices for environmental sensitivity and effects) and a decision tree technique. Parallel to this, a fuzzy logic model, which allows to merge expert's opinions per marine spatial compartments, is developed. To get input data for a fuzzy logic model an expert answers the question ”In case of an oil spill does usage of a given response method make more or less harm for the given compartment than no response” and evaluates it in a five-rank system. To answer the question, an expert follows modified flowchart for sNEBA matrixes, considers the information given in matrixes in the right order and forms an opinion; the latter is referred in input data table for the fuzzy logic model. Thus the development of a fuzzy logic model organises the flow of information. Finally, the model merges experts opinion about different compartments into one single score which represents the gross benefit if the single or combined response method is implemented.

The primal fuzzy logic model presented in this deliverable D5.7 (Fuzzy logic model for sNEBA) has generic membership functions and knowledge rules. In future applying model for specific geographical location and season, those could be accordingly adjusted.

1. Introduction

A Strategic Net Environmental Benefit Analysis (sNEBA) is a planning tool for oil spill response preparedness (deliverable D5.5). Present available oil spill response techniques include mechanical recovery, chemical dispersion of oil and in situ burning (burning of oil directly on the sea surface), but also doing nothing, and leave the oil to be natural dispersed and degraded, may be the (only) option. A sNEBA compiles information and data on 1) sensitivity of important ecological organisms in the selected sea area, 2) estimates for fate and distribution of oil spill in the selected sea area. One subgoal of sNEBA is to find a most proper oil spill combat technique which minimises the environmental impact of both oil spill and oil spill response techniques. This evaluation can be completed for all marine spatial compartments (sea surface, water column, seabed, and coast) by assessing the environmental pros and cons of the different oil spill response techniques relying on knowledge matrixes (D5.5) and decision tree technique. Parallel to this a fuzzy logic model which allows to merge knowledge of non-physical parameters or expert's opinion is developed. Finally, the estimates of the sNEBA tool bivalent approach and fuzzy logic approach are compared, and the applicability of fuzzy logic model inside of sNEBA tool will be decided.

2. Method

The advantage of using the fuzzy logic, introduced by Zadeh (1965), is the possibility of applying expert knowledge even if the required exact relationships (links) are not fully established. Building up a fuzzy logic model the knowledge expressed by physical quantities can be merged with knowledge of nonphysical parameters, human-made visual observations, empirical knowledge etc. In the content of this report the necessity to incorporate of non-physical quantities which could be presented in the way of ordered classes hints to the possibility to merge information using the fuzzy logic modelling principles.

2.1 Fuzzy logic modelling principles

A fuzzy logic modelling approach could be useful to incorporate different input quantities to one output quantity. Two or more affecting aspects (input quantities) related to an affected aspect (output quantity) form a relational system; all relational systems together form a relational scheme (Figure 1). The next 3 steps to build-up the model are: 1) fuzzification, in which the input data are translated to memberships of sets in qualitative terms, 2) fuzzy inference, in which a set of knowledge rules between classes of aspects are defined, and 3) defuzzification where the qualitative output of the model is translated into quantitative value if the latter is preferred. In the first step, by expert knowledge, the variables are expressed regarding an ordered set (or classes) of qualifications, e.g. low, middle and high in the sense of influence on the affected aspect. The defined membership function represents numerically the degree to which a value of an aspect belongs to a certain class. But instead of assigning a single qualification to a variable, the fuzzy logic allows for a variable to belong to several classes with corresponding membership values. In the second step, multiple knowledge rules are applied in parallel, each with its weight. The defuzzification step is needed to communicate the results if the numerical output is necessary.

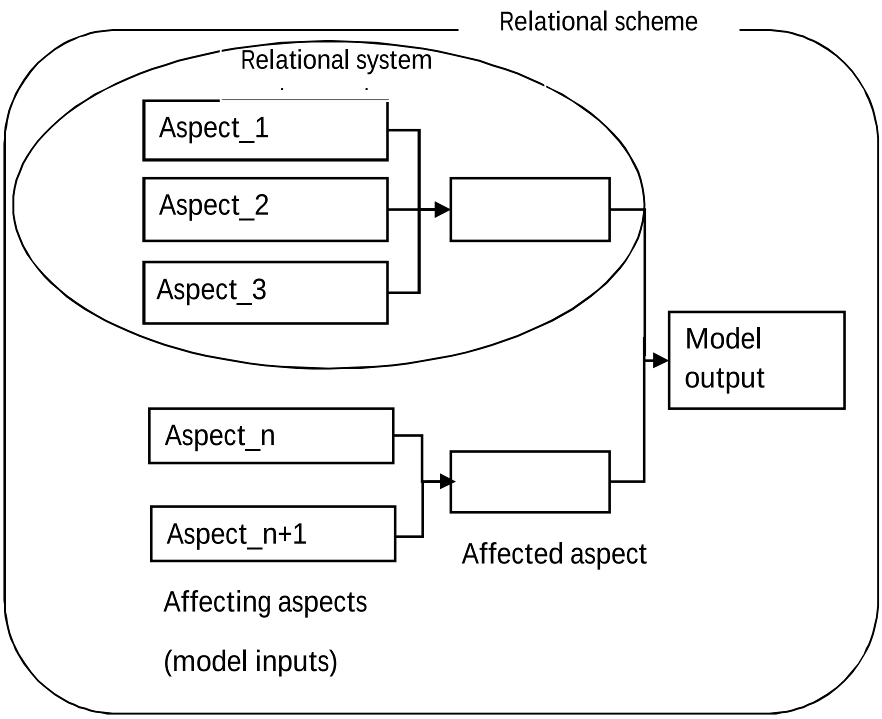

Figure 1. A general schematic representation of the relational scheme of the fuzzy logic model.

2.2 A conceptual fuzzy logic model

A conceptual fuzzy logic model is based on expert opinion which then is used as input information to a fuzzy logic model to integrate an expert knowledge. The latter is used to evaluate the total environmental benefit from interventions (e.g., mechanical recovery, in-situ burning and use of chemical dispersants) in case of an oil spill.

2.2.1 Forming an expert opinion

An expert will answer a question: in case of an oil spill, does usage of a given response method make more or less harm for the given environmental compartment than no response? In practice, an expert will fill an input data table with scores for every response method and every compartment similar to D5.5 MATRIX X3. However, the way how an expert reaches the score is different and also the score ranks (also look Wegeberg et al. 2017). Scores are given according to selection criteria (Table 1).

Table 1. Selection criteria and scores

Criteria for evaluation:	**Score**
Positive net environmental benefit	A
Rather positive environmental benefit	RA
Positive and negative environmental benefits are balanced	N
Rather negative environmental benefit	RC
Negative environmental benefit	C

An expert decides score considering the information given in matrixes (most of them are described in D5.5, and some are slightly modified). All matrixes are shortly explained in Table 2. Flowchart for sNEBA components (matrixes) given in D5.5 is modified to guide an expert through information (matrixes) in a proper way keeping in mind the score table of FLM (Figure 2).

Table 2. Matrices for environmental sensitivity and effects

Short name of matrix	**Explanation**	**Comments**
X1	Key/sensitive organisms	According to location and season
Y2	Eco-toxicological profiles and information for each spatial compartment	According to oil type and predefined concentration
X2	Potential environmental effects (pros/cons) for each spatial compartment	According to the response method used
$Y1_b$*	Contaminated areas for each spatial compartment (before response method used)	
$Y1_a$*	Contaminated areas for each spatial compartment (after response method used)	According to weather and ice concentration information
ΔY1*	The difference in polluted areas for each spatial compartment if the response method is used	According to weather and ice concentration information
Y3	Oil spill fate and damage reaction to a response method	
X3*	Each spatial compartment net environmental reaction to a response method	

*Notes that here the meaning of some matrixes is slightly modified in reference to D5.5 defined matrixes

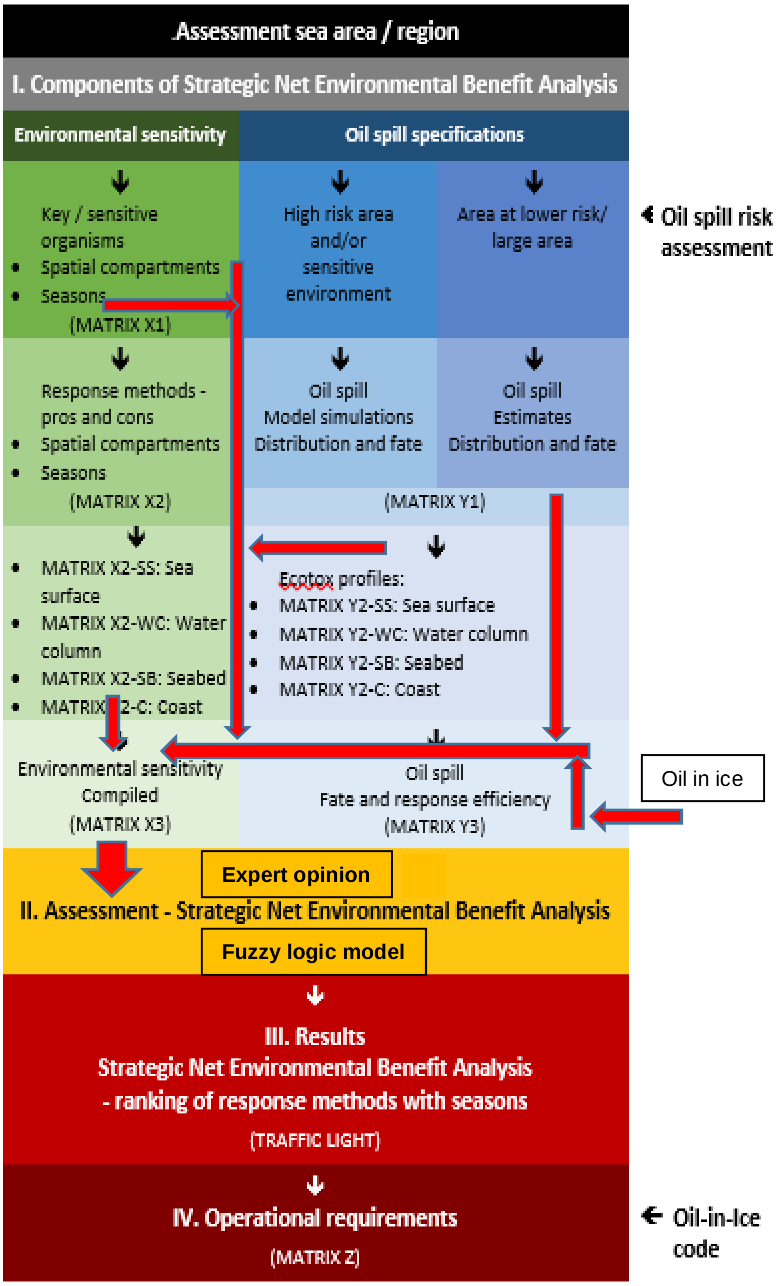

Figure 2. Modified flowchart for sNEBA matrixes involved in forming an expert opinion (also look D5.5, Figure1). The red arrows show how to get an expert opinion.

Thus, for a given location and season, an expert first incorporates knowledge in matrixes X1 and Y2, in next step first this knowledge is bound with information given in matrixes X2 and $Y1_b$*. This information is then compared with knowledge bound into matrixes X2 and $Y1_a$* (the latter consists information from Oil in Ice block and matrix Y3*). In that complex way the score is found for matrix X3* (Table 3). To follow the information flow, see the Figure 2 and Figure 3.

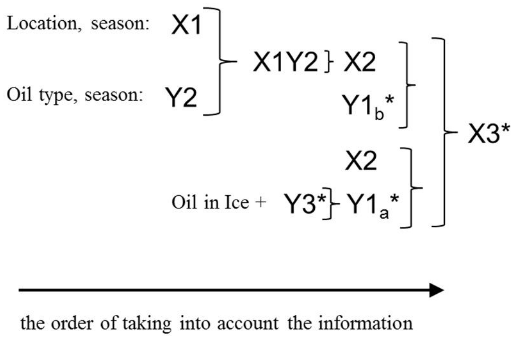

Figure 3. The order to consider information (alternative 1)

Table 3. Matrix X3*, an input information table for a fuzzy logic model (note that for this example the matrix is filled in only for response method ISB and for spring season)

Oil spill response method	**Season**	**Sea surface**	**Water column**	**Seabed**	**Coast**
ISB	Spring	A	RA	RA	A
	Summer				
	Autumn				
	Winter				
Mechanical recovery	Spring				
	Summer				
	Autumn				
	Winter				
Dispersion	Spring				
	Summer				
	Autumn				
	Winter				

An alternative 2 approach requires at first to incorporate knowledge of $Y1_b$* and $Y1_a$* to matrix ΔY1 to see discrepancies in oil spill spreading data before and after the response method applied. The matrix ΔY1 already includes information from Oil in Ice block and matrix X3. Next combined information of matrixes X2 and ΔY1 will be applied on combined information of matrixes X1 and Y2 to fill in table for matrix X3*. To follow the information flow in case of alternative 2, please see Figure 2 and Figure 4.

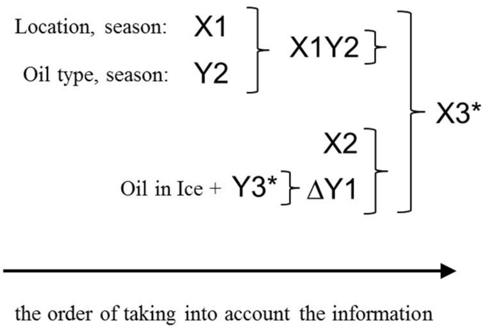

Figure 4. The order to consider information in case of an alternative 2.

2.2.2 A primal fuzzy logic model (FLM) for sNEBA

The FLM is meant to sum up the environmental benefits of different compartments if one or several response methods are implemented for combating an oil spill (to find a g*ross benefit* for the environment). We consider four different compartments (*sea surface, water column, seabed* and *coast* – as affecting aspects) to find *gross benefit* (affected aspect). The primal FLM relational system (in case of only one relational system this also represents a relational scheme) is given in Figure 5.

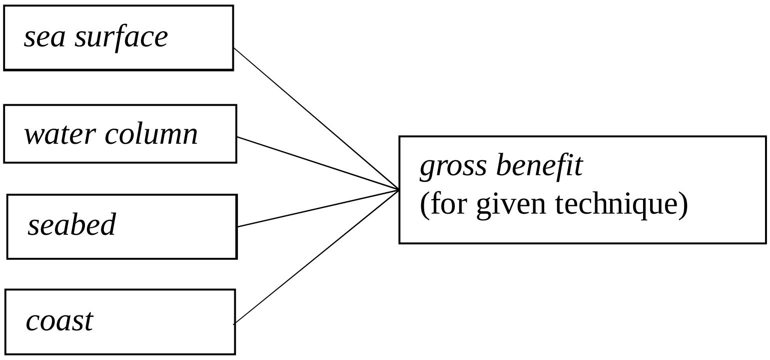

Figure 5. The FLM relational scheme.

However, relaying our previous experience (Lilover et al. 2006, Lilover and Laanemets 2006 and Lilover and Kõuts 2012) we suggest not to include more than 3 affecting aspects to one relational system (this helps to keep the knowledge rules readable). Therefore we propose to have two relational systems – just adding compartment *coast* impact separately (Figure 6).

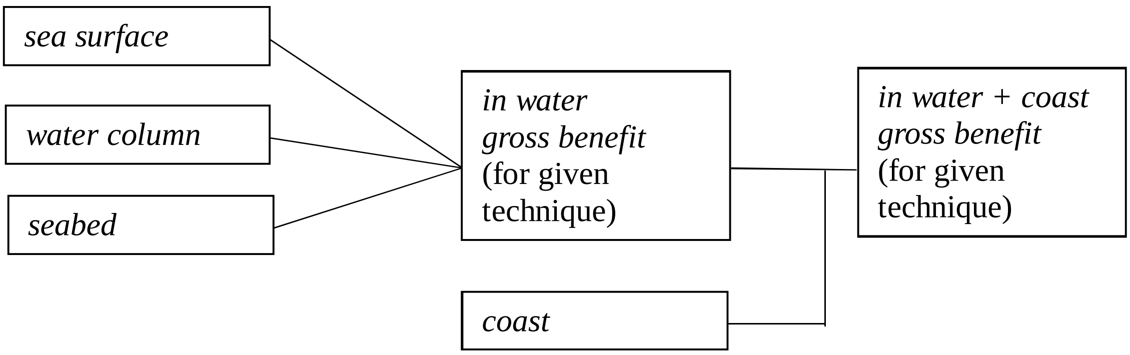

Figure 6. The FLM with two relational systems.

The output parameter of FLM is the *gross benefit* for given used technique (ISB, Mechanical recovery and Dispersion, if more than one response techniques will be used then combined technique *gross benefit* can be computed). Note that summarised benefit of techniques used in case of this primal FLM is found versus Do Nothing approach. Input/output parameters table could be presented as suggested in Table 4.

Table 4. An input/output information table for a FLM (note that for this example the matrix is filled in only for response method ISB and for spring season). The model summarises the benefit of the technique used versus Do nothing approach.

Oil spill response method	**Season**	**Sea surface**	**Water column**	**Seabed**	**Coast**	**Gross benefit**
ISB	Spring	A	RA	RA	A	**A**
	Summer					
	Autumn					
	Winter					
Mechanical recovery	Spring					
	Summer					
	Autumn					
	Winter					
Dispersion	Spring					
	Summer					
	Autumn					
	Winter					

*meanings of ranks are given in table 1

For primal FLM with two relational systems, we propose the following set of membership functions: *Negative*, *Neutral* and *Positive* (Figure 7). The division into classes of an affecting aspect is done according to a sense of influence to an affected aspect. So fuzzy logic allows membership of an affecting aspect in two classes at the same time. For example, if *water column* has ranking RA, then it means that it belongs with membership 0.5 to class *Positive* and with membership 0.5 to class *Neutral* (Figure 7). Note that membership functions could be similar for all input parameters (*sea surface*, *water column*, *seabed* and *coast*) but could also be individual if experts decide so. The ranks C, RC, N, RA and A could also be shifted in x-axis according to the experts best understanding as well as membership functions itself.

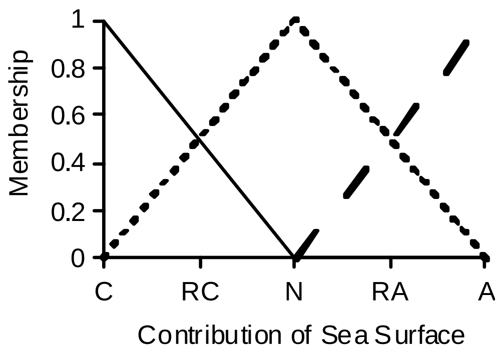

Figure 7. Membership functions for the input parameter (an aspect) *sea surface*. The classes *Negative*, *Neutral* and *Positive* are depicted as follows: solid line marks *Negative* class, the dotted line the *Neutral* class and the dashed line the *Positive* class. Membership functions could be similar or different for all input parameters (*sea surface*, *water column*, *seabed* and *coast*).

In the next step, fuzzy inference, a set of knowledge rules linking affecting aspects with the affected aspect is formed (they are so-called IF … THEN … rules). For primal FLM relational system, *in water gross benefit*, the rules are given in Table 5. For the second system, *in water + coast gross benefit*, the rules are given in Table 6.

Note that decision-making rules inside of fuzzy logic model could be differently defined for different response methods as well as for different locations (e.g. for Disco Bay and the Gulf of Finland). For example, if *coast* has priority over other compartments, it could be stated in the rules. Therefore for given technique and location, a primal FLM could be replaced by a unique FLM considering local specifics.

Table 5. Knowledge rules for the relational system *in water gross benefit* (aspects: s*ea surface, water column and seabed*)

System: *in water gross benefit*				
sea surface	*water column*	*seabed*	*in water gross benefit*	*in water gross benefit* Comments/ Change to*
Negative	Negative	Negative	Negative	
Negative	Negative	Neutral	Negative	
Negative	Negative	Positive	Neutral	
Negative	Positive	Negative	Neutral	
Negative	Positive	Neutral	Neutral	
Negative	Positive	Positive	Positive	
Negative	Neutral	Negative	Negative	
Negative	Neutral	Neutral	Neutral	
Negative	Neutral	Positive	Neutral	
Positive	Negative	Negative	Neutral	
Positive	Negative	Neutral	Neutral	
Positive	Negative	Positive	Positive	
Positive	Positive	Negative	Positive	
Positive	Positive	Neutral	Positive	
Positive	Positive	Positive	Positive	
Positive	Neutral	Negative	Neutral	
Positive	Neutral	Neutral	Positive	
Positive	Neutral	Positive	Positive	
Neutral	Negative	Negative	Negative	
Neutral	Negative	Neutral	Neutral	
Neutral	Negative	Positive	Neutral	
Neutral	Positive	Negative	Neutral	
Neutral	Positive	Neutral	Positive	
Neutral	Positive	Positive	Positive	
Neutral	Neutral	Negative	Neutral	
Neutral	Neutral	Neutral	Neutral	
Neutral	Neutral	Positive	Positive	

* here system *in water gross benefit* knowledge rules could differ for the Disko Bay and the Gulf of Finland as well as for different techniques used.

Table 6. Knowledge rules for the relational system *in water+coast gross benefit* (aspects: *in water gross benefit* and *coast*).

System: *in water+coast gross benefit*			
in water gross benefit	*coast*	*in water+coast gross benefit*	*in water+coast gross benefit* Comments/ Change to*
Negative	Negative	Negative	
Negative	Neutral	Negative	
Negative	Positive	Negative	
Neutral	Negative	Negative	
Neutral	Neutral	Neutral	
Neutral	Positive	Neutral	
Positive	Negative	Neutral	
Positive	Neutral	Positive	
Positive	Positive	Positive	

* here system *in water+coast gross benefit* knowledge rules could differ for the Disko Bay and the Gulf of Finland as well as for different techniques used.

3. Discussion and conclusion

In this deliverable, D5.7, the proposed information management order with the aim to provide the input data to the fuzzy logic model is generic. The presented fuzzy logic model is also generic, but its membership functions and knowledge rules are subjects to adjust according to specific geographical region or season. Thus, the location and seasonal relevance must be taken into account.

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