Multi-actor Dimensions and Cross System Levels Considerations in Spatial Decision Support

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Abstract

The spatial dimension of human settlements and establishments raises special decision problems in planning situations. Often there are multitudes of different criteria that have to be considered. Real world phenomena, in opposite to phenomena of an idealised mathematical or abstract world, are often vague, contradictory, and incomprehensible. Further, decisions about our physical environment often are of a multi criteria nature. We have in earlier research developed and tested the Ordered Weighted Average Procedure (OWA-procedure) for decision support in complex localisation decisions in physical planning outgoing from the basic methodologies for a multi criteria fuzzy decision support that already have been developed. However, the OWA-procedure in its current form is not able to capture the full complexity of most real decision situations. Some shortcomings of the OWA-procedure are its inability to consider several interesting parts and combine criteria from different system levels. For example, a location which is very suitable for an individual land owner or establisher may have severe drawbacks from the point of view of others stakeholders or even the whole community. In order to make OWA more suitable for those common situations the prototype is extended with functions for averaging between different value sets and cross level impact analysis.

Keywords: Multi Criteria Decisions, Fuzzy Measures, Ordered weighted average procedure, Decision Support, Negotiation Support Systems.

1 Introduction

Real world phenomena, in opposite to phenomena of an idealised mathematical or abstract world, are often vague, contradictory, and incomprehensible. However, in many cases it has proven favourable to handle such real life situations with a fuzzy approach (Klir 1996, Klir and Yuan 1995). Further, decisions about our physical environment often are of a multi criteria nature. However, Yager (1988) and Eastman

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and Jiang (1996) already have developed basic methodologies for a multi criteria fuzzy decision support. Based on those works, Holmberg (1997 and 1998), Asproth et al (1999), and Asproth and Håkansson (1999) have further developed and tested an Ordered Weighted Average Procedure (OWA-procedure) for decision support in complex localisation decisions in physical planning.

However, the OWA-procedure in its current form is not able to capture the full complexity of many real decision situations. For example, in most real world situations there are lots of decisions to be taken, not just one. Another common decision making situation is when more than one actor is involved, including competition and/or negotiation. A last shortcoming of the OWA-procedure is its inability to combine criteria from different system levels. For example, a location, which is very suitable for an individual landowner, may have severe drawbacks from the point of view of the whole community.

In order to make OWA more suitable for those common situations it needs among other things to be extended with functions for cross level impact analysis and multi layered trade off calculations as well as ability to average between different actors.

2 Challenge

Competition and negotiation processes are often characterised by conflicts of interests, the existence of various sources of information and rules, proper to each negotiator, a doubt about the sincerity and the good will of the other actors and exchanges of the bargaining type (Espinasse et al, 1997).

Hence, representatives for the society level have to take into consideration many conflicting interests, not only those of individuals and groups that express their opinions loud, but there are also silent members of the society that may have interest in the issue at stake. Due to this, the public interest has other criteria for localisation decisions than the individual landowner or establisher. The values of the joint criteria may also differ. Sometimes they even are quite contradictory. In order to handle this situation Asproth (2000) has described a prototype for handling Cross System Level considerations (CSL-tool)

Further, the individual landowner or establisher includes only the criteria that are of his or hers practical and economic matter for the localisation. There will often be conflicting interests between the individual and group system levels. For example, neighbours, competitors and members of environmental movements may have views that differ from the establisher's view, where a certain establishment is best localised. Håkansson (2000) has descibed a prototype for handling the Multi-Actor Dimension in physical planning and decision making (MAD-tool).

At last, when looking at the next system level, the society level, we find that there are much more to take into consideration. A localisation decision limits the possibilities to use the land for other purposes. In view of a longer time period, it is necessary to keep as many degrees of freedom as possible for future land use. In order to handle this situation Holmberg (2000) has described a Continuos Fuzzy Decision Management Tool (CFD-tool) for a prolonged time period.

3 Theoretical Framework

3.1 The OWA-procedure

3.1.1 Crisp Procedures

Traditionally two different procedures have been applied in decision processes of this type. First, the criteria are dichotomised into logical suitability values of, for example, "Yes" or "No". Those logical values are then combined by means of logical operators such as intersection, i.e., logical AND, or union, i.e., logical OR. The procedure is straightforward but, unfortunately, has two severe drawbacks. The first is that irrespective of where we draw the border, an incremental change in input may cause a drastic and big change in output, i.e., a jump from the set of suitable to the set of unsuitable locations will take place. Further, the logical operators are too blunt as instruments for this type of subtle judgements.

The intersection, for example, will constitute a too hard condition, i.e., a location which is perfect according to n-1 criteria will be excluded if it fails, due to an infinitesimal step, to fulfil just one of its requirements. The union operation, on the other hand, is far too liberal. Here it is enough if the location meets one of its criteria, irrespective how bad the values of the remaining ones are.

In a second approach, called the Weighted Linear Combination (WLC), continuous criteria are first normalised to a common numeric range and thereafter combined according to their weights of importance according to equation 1.

$$S_{wlc} = \sum wc_n / \sum w \quad (1)$$

S_{wlc} Suitability index
w Weight of importance
c_n Normalised criterion

Here we will receive a continuous s-value, i.e. we will avoid the abrupt jumps from one set to another. On the other hand, the rationale for just adding together various criteria may be highly questionable. Second, a single extreme value, far away from the common values, may influence the result in a not very logical way.

3.1.2 Fuzzy procedures

With help of fuzzy measures and fuzzy operations the strength of reasoning will increase and most of the drawbacks discussed above may be overcome. First, if the set of suitable locations is defined as a fuzzy set, a small change in input will just cause asmall change in membership grade, i.e. we will avoid the abrupt jumps between extremes.

Second, if the crisp intersection and union operation are replaced with their fuzzy counterparts, i.e. the t-norm and t-conorms, further advantages may be gained. Especially so if they are combined with fuzzy averaging operations, i.e. operations that for any given fuzzy set produces a new fuzzy set which is larger than any fuzzy intersection and smaller than any fuzzy union (Klir and Yuan, 1995). Hence, with a proper averaging operator it may be possible to avoid both the hard rigour of crisp AND-operations and the excessively liberal results of crisp OR-operations.

Further, it is also interesting to find a solution that permits trade-off between criteria, i.e. a good value in one variable may compensate for a bad value in another one. In this context the averaging operator can be seen as an ANDOR-operator which also provide full trade-off between criteria. A solution to this requirement is proposed by Yager (1988), who has presented a method called the Ordered Weighted Average (OWA) with continuous control over the degree of ANDOR-ness and with independent control over the degree of trade-off.

In OWA, criteria are sorted according to their rank order and special order weights, to be distinguished from criteria weights, are applied to those ranked criteria in order to achieve the desired degrees of ANDOR-ness and trade-off. Hence, ANDOR-ness is controlled by the degree of dispersion in the order weights, while trade-off is controlled by their amount of skew (Holmberg 1997). An overview of the OWA-procedure for choosing a good or optimal location is given in figure 1.

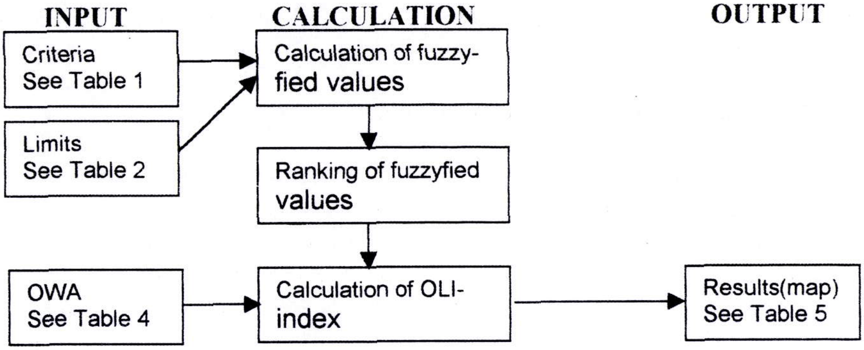

Fig 1: The OWA procedure

3.2 Negotiation Support Systems

The concept of Negotiation Support Systems (NSS) has been developed in later years and has increased in importance. NSS permits to join different points of view and positions, to conciliate differences and to suggest solutions for compromises. NSS is a communication support tool between the opposing interest parties. As an advanced tool in the negotiation process, it helps to identify the true interests, evaluate the importance, and to place them in the context of the confrontation with the other interests.

Raiffa (1982) and Bacow and Wheeler (1984) have presented some general principles for the negotiation process. Research findings on NSS success, presented by Nunamaker and Vogel (1987), include hardware and software settings in a multipurpose and flexible way, attention to the presentation support, and the possibilities to interact with the system on each individual's prerequisites. Espinasse et al (1997) have elaborated a NSS with a multi-criteria and multi-agent approach.

3.3 Living Systems Theory

Miller (1978) describes seven different levels of living systems. Though, he makes a reservation that there might be more levels, for example considers some researchers the community to be a level between the organisation and the society. In his book he also treats cross-level similarities and comparisons. One hypothesis is "Higher-level living systems in general have the emergent characteristics of more kinds and more complex combinations of adjustment processes than living systems at lower levels" Miller (1978).

4 A Multi-actor and Cross System Levels Prototype Design

As an example for the prototype a current project in Sweden, to find a suitable location for a factory, is chosen. A factory is depending on a number of factors for its operations. The most important are water and electricity supply, access to communications (roads and railroads), relatively far distance from residences, and possibilities to avoid negative environmental influence.

4.1 Multi-criteria decision situation with one actor

In the example the decision-maker, i.e. the establisher, has identified four geographical locations (Trångsviken, Vaplan, Hissmofors, Dvärsätt). The selection is made from locations that are possible for the establisher to acquire. Unsuitable locations are sorted out. In the next step, the establisher has to chose the best location based on the four criteria; nearness to water, electricity, railroads, and distance to residences (see Table 1). All four distances are expressed in meters. The map projection used for the locations is the Swedish National co-ordinate system (x,y).

Acceptable intervals for the distance criteria are given in Table 2.

Table 1: Criteria values and locations

Location	Water	Electricity	Railroad	Residence	X	Y
Trångsviken	120	2970	1500	1300	1414382	7022590
Vaplan	1200	300	600	750	1421028	7024999
Hissmofors	50	200	360	420	1434260	7025786
Dvärsätt	90	3480	260	400	1434974	7019356

In a first step the criteria values have to be transformed into fuzzy measures according to the fuzzyfication rules and principles expressed in table 2 and figure 2. To illustrate how these rules work, the calculation of the fuzzy measures for Trångsviken is shown as an example. In Trångsviken distance to railroad is 1500 meters, which is more than limit 2. Increase is set to False (close is better than far away) and therefor the fuzzy measure is 0. Distance to nearest residence is 1300 meters, which exceeds limit 2 for that criterion. Here the increase is True (more far away is better) and therefor the fuzzy measure is set to 1.

Distance to water is 120 meters, which is between the limits. Equation 2 is used for calculating the fuzzy measures for increasing criteria (true) and equation 3 for decreasing criteria (false). As distance to water is a decreasing criterion it is calculated according to equation 3. The result from the calculation is 0.98. Distance to electricity is 2970 meters, which is between the limits and the increase is false. Thus the fuzzy measure is calculated according to equation 3, with the result 0.01.

$$\text{Fuzzy measure} = (\text{Criteria value} - \text{limit1}) / (\text{limit2} - \text{limit1}) \quad (2)$$

$$\text{Fuzzy measure} = 1 - (\text{Criteria value} - \text{limit1}) / (\text{limit2} - \text{limit1}) \quad (3)$$

Table 2: Fuzzyfication parameters

Criteria	Limit 1	Limit 2	Increase
Water	100	1000	False
Electricity	300	3000	False
Railroad	300	1200	False
Residences	400	800	True

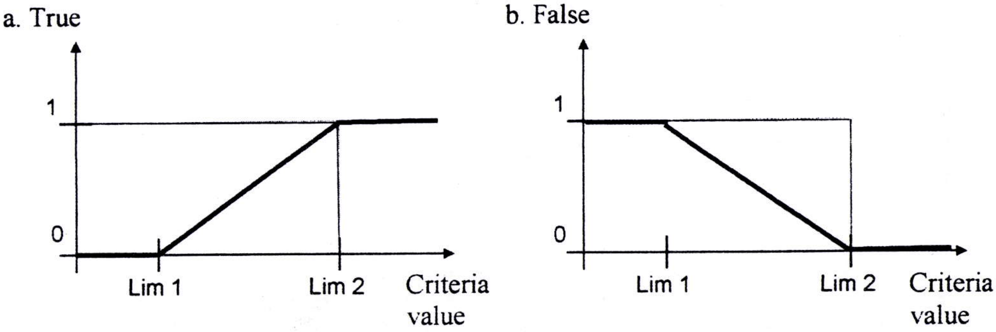

Fig 2: General form of the membership function used in calculating the fuzzy sets of good locations

Having obtained fuzzy numbers for the basic criteria, in the next step there is a need to calculate a crisp total ordering of those numbers. Several ranking methods are available for that calculation (Klir and Yuan, 1995). Here we have chosen to sort the fuzzy numbers in increasing order giving the results in Table 3. Table 4 shows five different combinations of order weights (OWA:s) to be used in the final calculation of Ordered Localisation Indicies (OLI:s).

Table 3*:* Ranked fuzzy measures for the four locations

Location	RFM1	RFM2	RFM3	RFM4
Trångsviken	0	0,01	0,98	1
Vaplan	0	0,67	0,88	1
Hissmofors	0,05	0,93	1	1
Dvärsätt	0	0	1	1

Table 4*:* Order weights applied in the five calculations

Run	OW1	OW2	OW3	OW4
1	1	0	0	0
2	0,25	0,25	0,25	0,25
3	0	0,5	0,5	0
4	0	0,2	0,2	0,6
5	0,6	0,2	0,2	0

Run 1 considers only the most negative ranked fuzzy measure (RFM) for each location. In run 2 all RFM:s have the same significance. In run 3 the best and the worst criteria are left without consideration. The two last runs have a certain skew toward good and bad values respectively. The Ranked ordered localisation indicies are calculated according to equation 4. The results obtained are summarised in table 5 and the map corresponding to run number 2 (all criteria having the same weight) is displayed in figure 3. Obviously Hissmofors is a good candidate from the establisher's point of view. Vaplan is a high ranking second best.

$$\mathrm{OLI} = \sum(\mathrm{RFM}_1 * \mathrm{OW}_1)\ldots(\mathrm{RFM}_n * \mathrm{OW}_n) \quad (4)$$

Table 5: Resulting Ordered Localisation indicies (OLI)

Location	Run 1	Run 2	Run 3	Run 4	Run 5
Trångsviken	0	0,5	0,49	0,8	0,2
Vaplan	0	0,64	0,77	0,91	0,31
Hissmofors	0.05	0,75	0,97	0,99	0,41
Dvärsätt	0	0,5	0,5	0,8	0,2

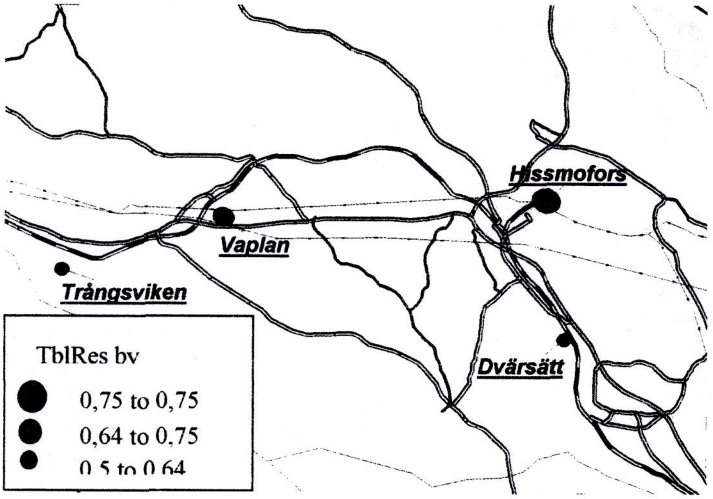

Fig 3: Map presentation showing results from establisher's run 2

4.2 Multi-criteria decision situation with more than one actor

In the first example there was only one actor, the establisher of the factory. For him, the localisation criteria to consider are the ones that are critical for making the factory functioning. He does not consider the consequences of other interesting parts. A conflict between interests may come up. As an example a group for environmental protection may consider nearness to natural reservations and to water very critical. Figure 4 shows how the OWA-procedure is modified for handling the Multi-actor dimension (MAD-procedure). In this procedure the actors and the establishers different criteria are considered in the calculation.

The "Actors weighted fuzzy measures" from the factory example can be calculated through weighting of the two (or more) different ranked fuzzified measures (eq. 5).

$$(W_{a1}, W_{a2}, \ldots. W_{an}) (RFM_{a1}, RFM_{a2}, \ldots.. RFM_{an}) = \mathbf{R} \qquad (5)$$

W	Weight
RMF	Ranked fuzzy measures
a1, a2	Actors

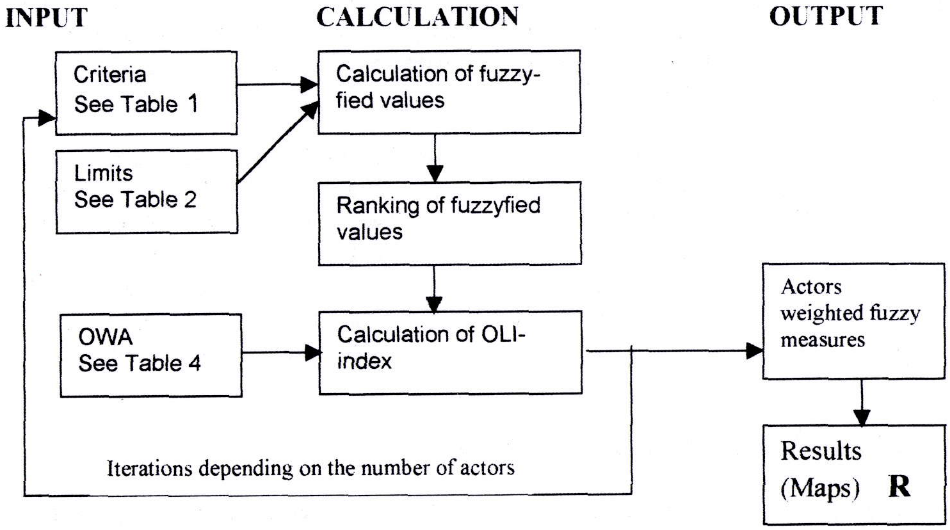

Fig 4: The MAD-procedure

In the example, the two actors have different criteria and different values of criteria. In the prototype it is possible to use different weight for each actor. The weights are used to set the priority between actors. Here, the actor who wants to establish the factory is given the weight 0,8 and the environmental protection group 0.2. The criteria of the second actor, the environmental protection group is shown in table 6 and the results in table 7-8.

Table 6: Fuzzification parameters for the second actor criteria

Criteria	Limit 1	Limit 2	Increase
Water	200	800	True
Railroad	200	1200	False
Residences	800	1200	True
Reservations	1000	2000	True

Table 7: Ranked fuzzy measures for the four Locations (second actor)

Location	RFM1	RFM2	RFM3	RFM4
Trångsviken	0	0	1	1
Vaplan	0	0,2	0,9	1
Hissmofors	0	0	0	1
Dvärsätt	0	0	0	1

Table 8: Resulting Ordered Localisation Indicies (OLI) (second actor)

Run1	Run2	Run3	Run4	Run5
0	0,50	0,50	0,80	0,20
0	0,60	0,55	0,82	0,22
0	0,25	0	0,60	0
0	0	0	0	0

In tables 9 and 10 we can see the results of the priority-weighted calculations. As can be seen, Vaplan is the best candidate from the second actor's view with Trångsviken as a high ranked second best. The weighted calculations places Hissmofors as the best alternative but Vaplan still is a high ranked second best, which also was the result of the calculations of the establisher's OLI.

Table 9: Ranked fuzzy measures for the Locations (weighted)

Location	RFM1	RFM2	RFM3	RFM4
Trångsviken	0,13	0,48	1	1
Vaplan	0,23	0,65	0,93	1
Hissmofors	0,30	0,81	0,95	1
Dvärsätt	0,20	0,42	0,66	1

Table 10: Resulting ordered Localisation Indicies (OLI) (weighted)

Run1	Run2	Run3	Run4	Run5
0	0,50	0,49	0,80	0,20
0	0,62	0,73	0,89	0,32
0,04	0,64	0,77	0,91	0,33
0	0,40	0,40	0,64	0,16

4.3 Multi-criteria decision at the society level

Decision-makers at society level have to make somewhat different considerations than the individual decision-makers. In the example, the society level is represented by the community. Some of the localisation criteria are relevant for the society level, but the values differ. As the community is, in some respect, responsible for water supply it is desirable to locate the factory close to water but on the other hand the legislation prevent localisation to close to water. Hence, the fuzzification function would look like figure 5 and equation 6.

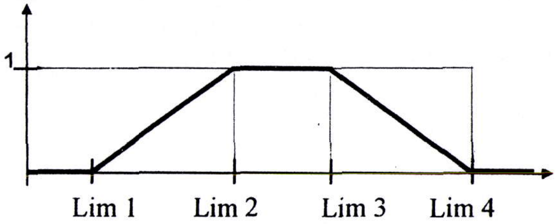

Figure 5: The function used in calculating the fuzzy set for distance to water

$CV <$ limit 1: $FM = 0$ (6)
Limit 1 $< CV <$ limit 2: $FM = (CV - limit1) / (limit2 - limit1)$
Limit 2 $< CV <$ limit 3: $FM = 1$
Limit 3 $< CV <$ limit 4: $FM = 1 - (CV - limit3) / (limit4 - limit3)$
$CV >$ limit 4: $FM = 0$

CV=Criteria value
FM=Fuzzy measure

Electricity supply is not a concern for the community so this criterion is insignificant in the community context. As it is of interest for the community to reduce lorry traffic, distance to railway is of interest. When it comes to distance to nearest residences the community has a more restrictive attitude. Another criterion that the community has to consider is natural and cultural protection areas.

As can be seen the results of the calculations of the different sets of criteria from the two different system levels are quite contradictory.

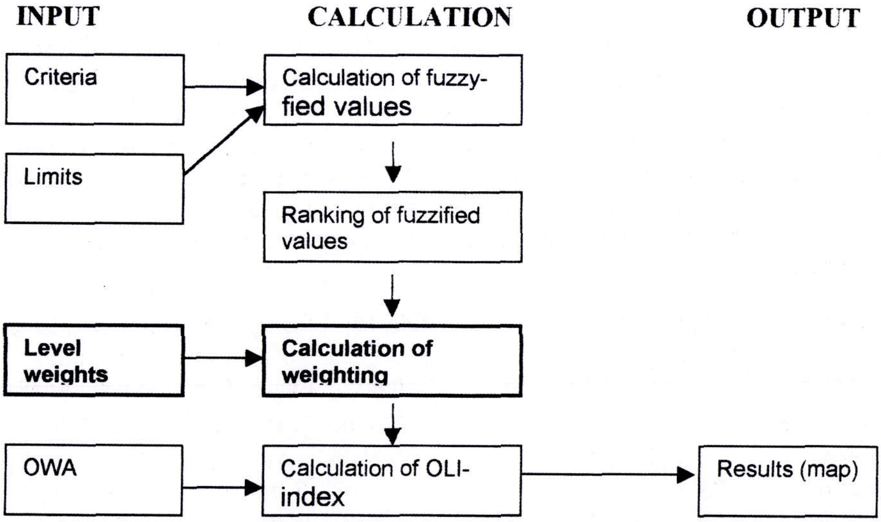

Fig 6: The Cross System Level Procedure

The results of the different runs can of course be used as a basis for discussion and negotiation. Here though, we will try to get a bit further through weighting of the two different ranked fuzzified measures according to equation 7.

$$(W_i, W_c)\ [RFM_i, RFM_c,] = R \qquad (7)$$

W	Weight
RFM	Ranked fuzzy measures
i	individual
c	community

The CSL-procedure, which is an extension of the OWA-procedure, is described in figure 6. The new steps are bold-marked.

Table 11: Fuzzification parameters for the society level criteria

Criteria	Limit 1	Limit 2	Increase
Water	75	200	True
Water	400	1000	False
Railroad	300	1200	False
Residences	800	1200	True
Reservations	500	1000	True

Table 12: Ranked fuzzy measures for the four Locations

Location	RFM1	RFM2	RFM3	RFM4
Trångsviken	0	0,2	1	1
Vaplan	0	0	0,5	1
Hissmofors	0	0	0	0.9
Dvärsätt	0	0	0	1

Table 13: Resulting Ordered Localisation Indices (OLI)

Run 1	Run 2	Run 3	Run 4	Run 5
0	0,55	0,6	0,84	0,14
0	0,38	0,25	0,7	0,1
0	0,23	0	0,54	0
0	0,25	0	0,6	0

In the example the two system levels had different criteria and different values of the criteria. In the prototype it is possible to use different weight for the two system levels. The weights are used to emphasise the importance of any of the levels. In this example I have chosen to set the same weight on both. It is possible that the society level should have higher weights. Table 14 shows the results of the weighting.

I have used the same order weights as in the foregoing calculations. The results of the five runs are presented in table 15.

Table 14: Level weighted ranked fuzzy measures

Location	RF1	RF2	RF3	RF4
Trångsviken	0	0,11	0,99	1
Vaplan	0	0,34	0,69	1
Hissmofors	0,03	0,47	0,5	1
Dvärsätt	0	0	0,5	1

Table 15: Resulting Ordered Localisation indices (OLI) of cross level calculation

Run1	Run2	Run3	Run4	Run5
0	0,42	0,55	0,82	0,21
0	0,41	0,50	0,81	0.21
0	0,39	0,49	0,76	0,21
0	0,30	0,25	0,70	1,10

Figures 7 to 10 show some of the corresponding maps.

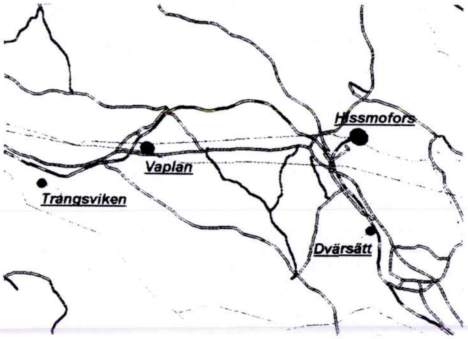

Fig 7: Map presentation of the establisher's OLI:s in run

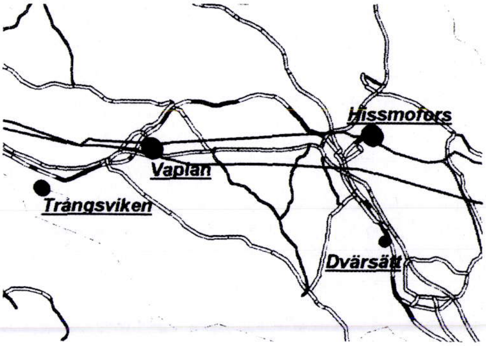

Fig 8: Map presentation of the weighted OLI:s of the two actors in run 2

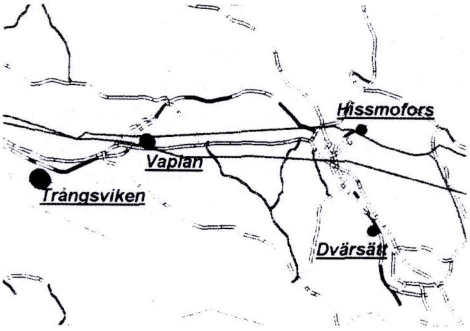

Fig 9: Map presentation showing results from community's run 2

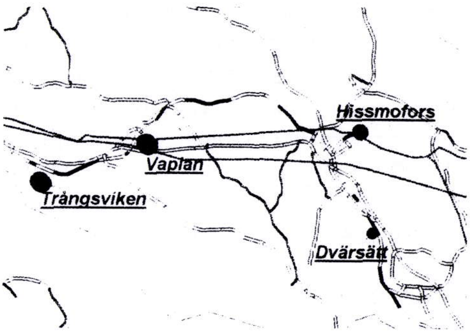

Fig 10: Map presentation of the cross level weighted OLI:s in run 2

In a first glance at the results from the different sets of runs, one can get the opinion that the outcomes are quite contradictory. In a further analysis and discussion however, one can see some feasible solutions to agree on. This shows the potential of a tool for handling multi-actor dimensions and cross system level considerations.

5 Conclusions

The discussions and examples in this paper have confidently demonstrated that the original OWA-procedure can be extended and improved in different ways. However, the extension into the multi-actor dimension and the cross level impact analysis, which has been derived here will not be sufficient for real life usability. Nor is it shown that the extension proposed here is the best one. So far it may just be seen as a possible one.

In addition to the extension over different system levels and the combination of different value sets, Holmberg (2000) has extended the time dimension. Hence, a natural next step will be to combine those three approaches into a combined tool being able to handle the time dimension, the cross level, and the multiple values together. Demography and the dynamics of peoples movements, as described in Asproth and Håkansson (1995; 1997), are usual localisation criteria for the society level. These aspects ought also to be included in future assessment tools. Anyhow, some work remains before we have a completely generic decision tool.

Further, here decision support has been discussed in isolation. However, as Simon (1995) has pointed out, decision making is just a minor part of the total design process. Hence, another evident step is to incorporate the work presented here, together with the works of Holmberg (2000) into a superior design support procedure or methodology, for example the Methodological and Epistomological Engines discoursed by Agrell at al (1996).

To calculate the consequences in other system levels is a problem where anticipatory approaches obviously can make a great contribution.

The method that is developed here is based on Yager (1988) who has developed a fuzzy method based on Zadeh (1965). To further evaluate the method, a comparison with traditional OR-methods, for example ELECTRE, would be of interest.

At last, in the present version of the procedure the number of options remaining for future decisions is estimated by subjective common sense reasoning. In many cases that may be sufficiently accurate but it may also be occasions that require more elaborated estimates. Here anticipatory procedures, procedures or systems for which the present behaviour is based on past and/or present events but also on future events built from these past, present and future events (Dubois 2000), emerge as an interesting and promising approach to incorporate into the procedure.

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