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SOME POSSIBILITIES FOR CONSTRUCTION OF LINGUISTIC VARIABLES FOR SUSTAINABLE DEVELOPMENT DECISION-MAKING

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Abstract: The fuzzy logic is found to be useful tool for Sustainable Development (SD) decision making because they could express uncertainty, either in informational and in the decision-making environment. The general linguistic definition, acceptability for environment (air, water, nature, risk, etc.), as well other aspects of sustainable development (health, management issues, etc) is proved to be useful in approximate reasoning and decision-making. According to this definition, the various fuzzy functions of environmental acceptability could be constructed.

The foundation for such construction is the concept of special kinds of fuzzy functions generally defined as linguistic variables (LV), which are suitable for mapping to fuzzy sets. As domain for such functions, various SD indicators could be used, expressed either in their physical values (e.g. production, emissions, risk of accidents) or in measures of preferences (MP). The most important MP are mentioned: Stated Preferences economic evaluation of environment (SPT), economic instruments of environmental protection mostly based on Revealed Preference Techniques (RPT), preferences scales (ordinal, cardinal) according to various methods of their construction, etc.

Also, possibility theory (analogous to probability) could be exploited in such construction. It could be used together with environmental engineering modelling formulas for the purpose of determinations of fuzzy functions. The appropriate forms of linguistic variables considering limit cases for the purpose are also discussed.

Key-words: fuzzy logic; fuzzy functions; indicators; linguistic variables (LV), measures of preferences (MP); linguistic scales; possibility theory.

1. Introduction

It was stated before (rumenjak, 2004) that pessimistic form of general decision making equation (Resnick, 1981) is suitable for non-utilitarian decision making paradigm for the environment:

$$U_D(a^*) = max_i \, min_j \, D_{ij} \qquad (1)$$

where:

$U_D(a^*)$: Final choice (based on specifically defined MP)

Dij: General defuzzifier that could be expressed in: MP, products of probabilities and MP, resulting values of fuzzy implication systems or utilitarian sub-systems expressed either in fuzzy form (pairs with scalars or vectors) or defuzzified, etc. under (for) each criterion

$_{i,j}$: Indices denoting alternatives and criteria, respectively

In the case of fuzzy logic modification of that equation, construction of appropriate fuzzy functions for LV, that determine part D_{ij} of the equation (1), has to be considered. These functions are called membership functions (MS) of appropriate arguments and could be of continuous and discrete type or singletons. Wider approach for selecting arguments for such functions is recommended here, including those that are still under consideration. For the moment, the most of the interest is laid down on those methods that are already used in decision making for the environmental matters in the mineral industry.

The possibility that offers fuzzy system approach is the simple connection of various argumental domains of LVs in integrated decision making system.

2. Construction of Linguistic Variables

2.1 The general form of LV acceptability for environment and SD

The general form of LV, Acceptability for environment, as the aspect or part of SD, which proved to be of interest, is shown in Figure 1. Such set has to be partitioned in acceptability and non-acceptability parts or subsets.

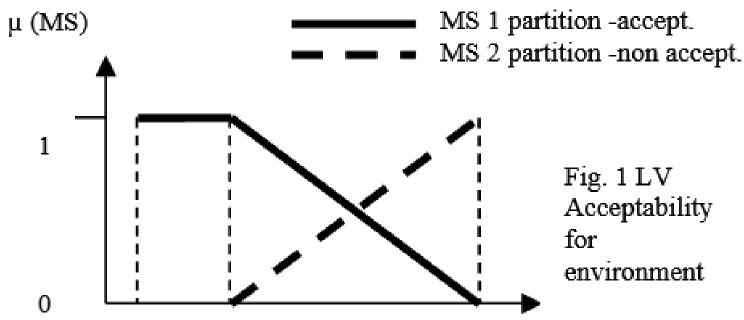

Fig.1 - Specific measures of impact indicator or MP

The argumental domain for functions (or MS functions) are always some SD (consumption stream) indicators (Dasgupta, 2001), which could come either expressed in their real (specific or physical) values or as various MP. MP could be represented by various scales (of ordinal or cardinal type) or could be of economic type. It is easy to show that economic type of MP (either money evaluation or money generalization, as Special Drawing Rights) is a special case of ratio scale that deserves to be treated separately. In cases when the indicators belong to the category of indicators of impact, the values of MP could be, according to the applied conventions, negative, but for the decision-making they have to be arranged in the direction of positive evaluation of criteria. It is very convenient to speak of linguistic scales, as another definition for partitioned LVs, because of logical and smooth transition between fuzzy subsets and other types of scales. The methods have to be developed for transforming cardinal and ordinal types of scales to linguistic scales or LVs.

The special form of LV are singletons, defined as discrete members of fuzzy sets, which could be of special interest for transformation of results from some common non-fuzzy methods to fuzzy values. LVs with the physical values of indicators as arguments could be readily constructed on the basis of preferences or other considerations and this will be not, except in the case of environmental engineering models, dealt here.

2.2 Some non-fuzzy methods for decision making in mineral industry

Only few methods of decision-making are specifically intended for mineral industry. All declared the use of various scale of MP (ordinal or ratio scale) and define the methods of aggregation of results.

Method of Vulnerability of Environment with Matrix of Interactions (Koblar,1996) is relatively widespread in Croatia and in neighboring Slovenia, where it originated. It defines parametric scales or basic parameters (from 1 to 5) for specific part of environment (sub-criteria) and parts of technological operations. The aggregation could be performed either over group of criteria and/or main parts of technological operations. The range bands for aggregation of results are defined.

Method of Reshaping and Reclamation (MRR) is recently suggested (Krasić, 2005). It defines 40 indicators in ordinal/ratio ranges from 1 to 3 or sometimes 5, divided in three main groups: natural, economical-technical and ecological. The aggregation is similarly done as at previous method. The range bands for aggregation are also defined in the method.

There is also use of some not specially defined methods of multicriteria analysis with ordinal/ratio scales (often scales in range 1 to 10), which are created depending on particular cases. The main problem at such methods is ill-prepared scales and lack of consensus of stakeholders about definition of scales, which often results in low credibility of the applied method.

Rapid Impact Assessment Matrix or RIAM method (Jensen, 1998) is not yet amongst those used in mineral industry, but its use has already been considered and recommended, also in its fuzzy form (Rumenjak, 2004). It is a very sensitive multi-scale method, using simultaneously 5 different scales for the evaluation. Because of its inherent sensitivity it could be used for every specific decision criteria or sub-criteria in SD. The aggregation is done differently from previously mentioned methods, by comparison frequencies of all resulting range for alternatives.

2.3 Ways of transformation of existing methods (scales) to LV

The main advantage of using existing methods for transformation to fuzzy logic systems obviously is a certain level of acceptance of existing methods within the expert community. They could also help creating such LV that would be less case dependent because they are based on previous experience. The used ordinal or cardinal scales of MP could be easily transformed to fuzzy scales. The simple example of transform to LVs includes expression based on Laplace-Bayes criteria (Hastie, 2001):

$$\frac{i-1/2}{M}, \qquad (2)$$

where

i: Ordinal value,
M: Upper value of ordinal scale

is chosen from the MRR method and it is shown in Fig. 2.

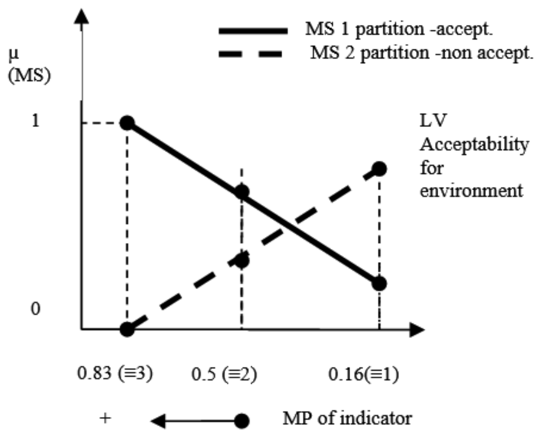

Fig. 2 Transformation to LV Acceptability for environment of existing method with compared original ordinal values in parenthesis

The basic transformation of values from ordinal or ratio scale could be done to singletons, obeying the extension principle. Obtained singletons could be used in recently suggested utilitarian subsystems of decision–making (Rumenjak, 2006), according to the rules of fuzzy arithmetic. The final result of fuzzy arithmetic operations could be also used in implication subsystem for decision-making or directly in decision equation.

RIAM, opposite to previously mentioned methods, could use the whole range of its original scale for describing part of SD consumption stream of importance and therefore it is convenient for defining the continuous fuzzy set for LV, instead that of discrete or singleton type. Opposite to previous methods, the resultant range bands from aggregation operations for RIAM method are not defined and it is therefore not recommendable to use fuzzy arithmetic operations (addition) for aggregation. So, the results from original method evaluation in RIAM have to be incorporated in continuous LV and use them in implication subsystems.

2.4 Economic values for use in fuzzy systems (Stated Preferences and Revealed Preferences Techniques)

Stated Preferences (SPT) and Revealed Preferences Techniques (RPT) are main groups of techniques (Bateman, 2002) that could be applied as sources of economic values for arguments of LV, where non-market evaluation is needed.

Benefit Transfer (BT) is the technique for transfer values obtained by SPT and RPT to other locations and time. Because of its basic simplicity, BT it is widely used. A lot of theoretical considerations have been put to its proper use (Burton, 1999).

The way of construction of LV with such arguments could exploit the occasion that results of SPT and RPT evaluation are often bounded between two limit values (upper and lower) or have some statistical description. This could be used during construction, enabling determination of points with at least two grades of membership that could directed the construction of membership grades for other values of arguments.

2.5 Models of environmental engineering

Generally, the fuzzy system could be recognized as knowledge (or expert)-based, modeling based and hybrid system. The knowledge based system depends on implication (IF…THEN rules) and still it is more widespread. The modeling system is based on the rules of fuzzy mathematics. The hybrid system could be combination of both. Some considerations and methods for construction of hybrid systems are given (Rumenjak, 2005). One way of using indicators in construction of LVs in hybrid system is using models of environmental engineering.

The simple (box) model for air pollution concentrations from open pit mining is described by formula:

$$C_{ss} = \frac{Q_m}{UWH_m}, \qquad (3)$$

where:

C_{ss}: Steady state concentration,
U: Air stream velocity,
W: Width of the site perpendicular to air stream,
H_{m}: Mixing height
Q_{m}: Unit area emission

The same basic structure of probability and possibility distributions could be exploited enabling constructing fuzzy sets from known probability distributions. It is possible to construct possibility distribution from existing continuous probability distribution and use it in fuzzy models. In this case, the mixing height (H_m), but also emission per unit area (Q_m) and air velocity (U) could be described by possibility distributions.

The simple construction of LV could be performed using limit values from the environmental standards as a distance points, but more elaborate methods of construction, using entropy principle or Bayes rule, could be also applied (Ross, 1995).

2.6 Sensitivity question in construction of LV

Usually, sensitivity matters in fuzzy decision making could be dealt by linguistic hedges (kind of transforms), which effectively change previously constructed LVs according to the perception of sensitivity of part of environment. The question of linguistic hedges is much elaborated in literature (Cox, 1999). But, in the cases when only nominal (or unordered categorial) variables are on disposal, partition based again on Laplace-Bayes criteria of equality seems to be appropriate. The denser and equally distributed partition could be applied as the best estimation. Those partitions are based on variety of linguistic terms that could appear during expression of sensitivity situations (conditions). The Fig. 3 shows the case with such partitions. The solution of implication system, either fuzzy or non-fuzzy with defuzzification, could be based only on few discrete values on position scale which could minimize uncertainty.

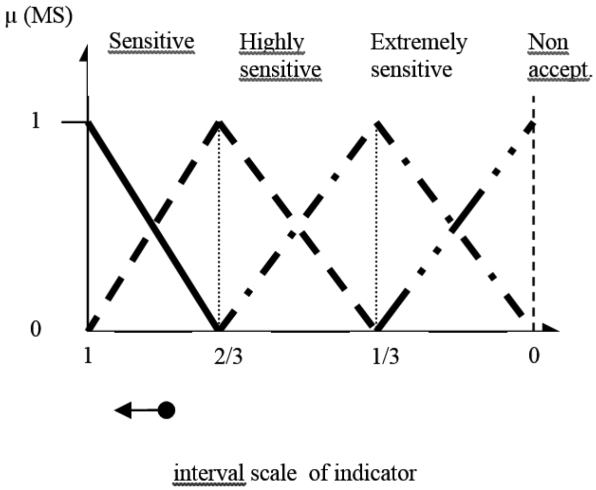

Fig. 3 LV Acceptability for Environment with denser partitions for the case of higher sensitivity

2.7 Non- standard cases of LV

Some cases have been recognized during construction of LV that could be described only by non-standard fuzzy sets or singletons. The first is the question of non-convex sets that could appear in general and environmental economics (Sydsæter, 2005, Goodstein, 2003). The non-standard set for this case could be described by formula (Demico, 2004):

$$A: X \rightarrow CI \qquad (4)$$

where:

A: fuzzy function
X: arguments (e.g. economic values)
CI: crisp set of MS values defined on closed interval

The LV in the case of non-convexity, with economic values as arguments, which could be of use in decision-making, is shown in Fig. 4.

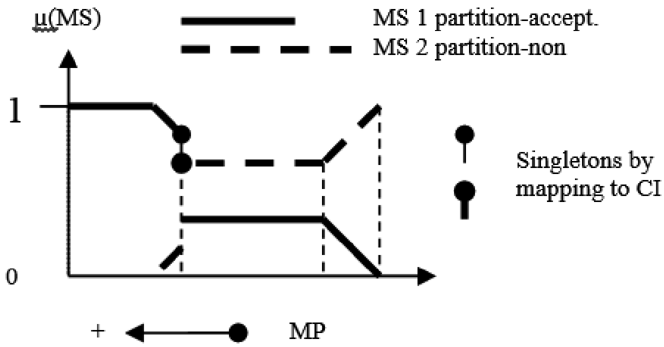

Fig 4. Non-convex LV represented by non-standard fuzzy set

The simple solution of the case is performing mathematical/logical operations at lower values of MS in the point of non-standard representation.

The second is the matter of defuzzification in implication systems which are the part of decision-making system. Often significant differences in number of LVs in implication systems, with resulting information inequalities of such subsystems, could be expressed by fuzzy set of higher order, described by following formula:

$$A: X \rightarrow FI \qquad (5)$$

where:

FI: fuzzy set of MS values defined on closed interval

The use of such a set could help in decision-making in the way that could decrease the influence of differences in informational content of implication systems.

3. Conclusions

Construction of LVs for SD decision-making could be performed using the various consumption stream indicators. Two recognizable cases of choosing arguments for LVs are physical measures of indicators and MP.

The existing methods are the best candidates for transformations to methods with LVs, exploiting the fact that those methods already have their place in SD decision making in mineral industry or are very suitable for doing this.

Cases of non-convex set and information inequalities of implication subsystems could be dealt effectively by using non-standard fuzzy sets.

Variety of possibilities, considering hybrid systems in decision making combining implications systems and models of environmental engineering are still open for research.

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