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Fuzzy Sets and Decision Making in Nuclear Science

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ABSTRACT: Fuzzy set theory has been extensively researched in various fields of engineering. In nuclear science, a significant influence of fuzzy sets can be noticed. However, applications of fuzzy set theory to nuclear engineering is novel. In this paper, we start with a basic statement of the decision-making process based on fuzzy set theory, and then apply it to nuclear science with some practical applications (a fuzzy decision making in an accidental release to the atmosphere as well as in a problem of land suitability classification). We believe that the use of fuzzy set theory in nuclear science has potential advantages.

Introduction

In almost all engineering activity, one is faced with decision-making. The search for better tools for decision analysis is an unending one. The rapidly growing number of applications of fuzzy set theory [5,15,16] suggests that it represents a natural development in the field of nuclear science of our understanding of how humans can reason effectively within a vague and fuzzy environment. The significant influence of this new theory in this area becomes clear from a glance through INIS (International Nuclear Information Systems). With respect to various disciplines of nuclear applications, a lot of work has been done on the investigations of the potential of fuzzy sets and related approaches for the field of nuclear science and continue to develop. The best well known work in this area is particularly topical, as it deals with the Chernobyl accident in which fuzzy human reliability analyses in man-machine systems have been considered [6,7]. The ideas developed by the above work could be useful in a broader context, and it is worthwhile to see how the relevant concepts are related to those of fuzzy set theory. Moreover, fuzzy set theory can take into account the imprecision of the factors affecting decision making in nuclear science. Hitherto known studies constitutes merely the initial investigation of a fuzzy-logical qualification of the uncertainty in risk and reliability assessment that arises as a consequence of the vagueness attached to expert judgement and seems incomplete. An answer to the question "how safe is safe enough?" for example, may be cast ideally in a fuzzy logic context since safety is by no means a crisp concept. Hence, the potential contribution of fuzzy set theory techniques towards the issues of safety criteria and regulatory decision making is significant. The use of fuzzy set theory in the decision process has been investigated by many researchers. As reported recently [4], the main advantage of using fuzzy set theory has been in overcoming the difficulties of decision making in a fuzzy situation represented by ill-defined terms. The inherent imprecision of such terms makes crisp ranking very difficult and application of statistical decision theory doubtful. The situation can be handled by the analyst by ranking these quantities verbal, which is the normal behaviour of human beings to account for inherent imprecision. Verbal ranking is then represented by fuzzy sets. The final ranking of alternatives from best to worst can be obtained using fuzzy operations.

Present investigation first starts with a basic statement of the decision-making process formulated by Bellman and Zadeh (1970), and then places it in the general setting of fuzzy sets, applying them further into a decision aiding system in an accidental release to the atmosphere as well as in a problem of land suitability classification.

1 Decision theory: decision making in fuzzy environments

The literature is quite extensive for formulating the problem of decision making in terms of fuzzy sets [1,2,8,14,16]. The basic idea of a model suggested by Bellman and Zadeh for decision making in a fuzzy environment is as follows:

The fuzzy objective function is characterized by its membership function and so are the constraints. The decision in a fuzzy environment can therefore be viewed as the intersection of fuzzy constraints and fuzzy objective function(s).

More formally, let X denote a space in which all goals and constraints are defined. (a one-step decision process is considered in which the ideas can also be applied to the multi-step situation). All are represented in terms of fuzzy sets. Thus for 'n' goals $G_1, G_2, \ldots, G_n$ and 'm' constraints $C_1, C_2, \ldots, C_m$:

$$G_1, G_2, \ldots, G_n; C_1, C_2, \ldots, C_m : X \rightarrow [0,1] \quad (1)$$

A decision to be made is also a fuzzy set D, $D : X \rightarrow [0,1]$, so that it results from all the objectives (1).

$$D = f(G_1, G_2, \ldots, G_n, C_1, C_2, \ldots, C_m) \quad (2)$$

where 'f' expresses ties with the fuzzy set of decision D, 'f' would result from a translation of this statement:
the decision must result from a satisfaction of *all* objective, i.e. *all* the goals and constraints.

$$D = T(G_1, G_2, \ldots, G_n, C_1, C_2, \ldots, C_m) \quad (3)$$

where T is an extension of t-norm [9,10]. T was specified as minimum [1]. The model of the intersection of fuzzy sets might in certain contexts not be the min-operator but rather the product-operator or others [1,16]. Furthermore, the intersection might not even be the appropriate model of the "and" and it seems better to take the confluence of goals and constraints into account rather than of the intersection, and so on.

2 Decision aiding system in an accidental release to the atmosphere

The development of emergency response systems, which are able to support decision making in the event of a nuclear accident, is a relatively new area of R & D work, only a small number of systems are already in operation and, in general, they can only respond to a limited number of questions posed by a decision maker.

During the early stages of an accidental release of radioactive material to the atmosphere, the immediate aims of the off-site emergency management scheme are twofold: firstly, to determine the extent of any contamination occurring close to the site (i.e. out of a few km) for purposes of protecting the local public; secondly, to provide early estimates of the source term and hence permit consequences farther afield to be assessed. The source term module has the task to supply the system with all information concerning the release of radionuclides. However, the exact reconstruction of the source term is up to now an unresolved problem. Several mathematical methods are under development for atmospheric dispersion models. Some of them already give results with acceptable accuracy in special but not too complex situations. A direct application of the methods used for probabilities assessments of accident consequence is not suitable, since time consuming calculations are not feasible during an emergency and the nature of the uncertainties in a large fraction of the input information and model predictions differs fundamentally. Therefore, we seek another approach based on fuzzy sets and decision theory to treat uncertain information (incomplete and inexact). For example, the ambiguous problem of the classification with linguistic values such as very good, good, middle, bad and very bad according to the ratio of predictions and observation data can be treated with membership functions. Also a simple fuzzy algorithm is designed for the system to provide a reasonable solution for the practical users, which could propose different solutions from the view of practice.

The basic idea of the system is built on the following simple mathematical model:

$$\begin{aligned} C &= \frac{Q}{\pi u \sigma_y(x)\sigma_z(x)} exp(-\frac{y^2}{2\sigma_y{}^2(x)}) \\ x &= x(D) \\ y &= y(D) \end{aligned} \quad (4)$$

In the above equation, C is the concentration of radioactive material, which is dependent of an unknown source term Q and an unknown wind direction D (x and y are coordinates depending on the wind direction D, and the other physical parameters are given in this study case). In a real situation, we can on the one hand obtain by means of observation (O) measured concentration data denoted as $C_m^{(k)}$ for certain points ($k \in \{1, 2, \ldots, n\}$), and on the other hand we can calculate prediction (P) denoted as $C_{(i,j)}^{(k)}$ by the model if the source term Q and the wind direction D are given for the same points as used in the observation. For each point k, we define a fuzzy set F_k as

$$F_k = \frac{1}{1 + |C_m^{(k)} - C_{(i,j)}^{(k)}|} \quad (5)$$

where the indexes i, j correspond to the grids of the wind direction and the source term, i.e. $d_i = d_1 + (i-1)\Delta d$, $q_j = q_1 + (j-1)\Delta q$. The fuzzy set F_k can be interpreted as in a certain point k, the prediction P is the closest to the observation O. For all points, using the decision theory mentioned before, we obtain the fuzzy decision set D as:

$$D = \bigcap_{k=1}^{n} F_k \quad (6)$$

The best source term q_0 and the best wind direction d_0 can be obtained by using the defuzzification techniques. From a practical point of view, we can set the finite grids for wind direction since we more-or-less know the range of it. But we do not have any idea of the source term. If we set a large range of it, then we face the computer time-consuming problem for this simulation. For that reason, we use the concept of ratios of $\frac{P}{O}$ (prediction over observation), the situation for which all these ratios (for all measurement points) are as close to 1 as possible is being searched with respect to the different membership functions. In this way, we can get an approximate value of the source, therefore a more-or-less correct range of it. Several examples have been tested and the method proposed here seems acceptable from the point of view of the practice [13]. A flow chart of the system is depicted in Figure 1.

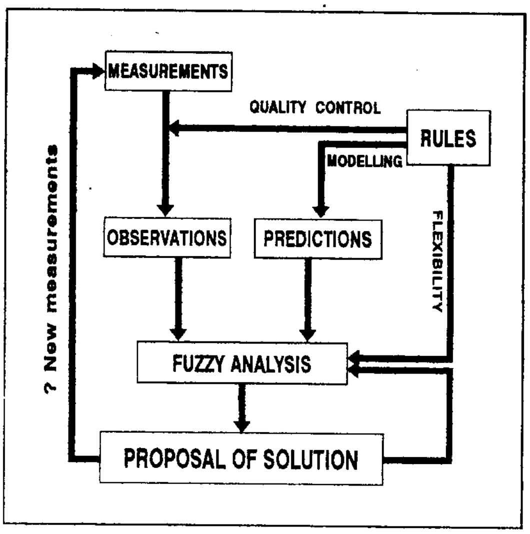

Figure 1: Fuzzy system shows a global diagnosis of the situation.

3 Land suitability classification

Land evaluation is concerned with the assessment of land performance for specified land utilization purposes. Such evaluation is essential in the process of land use planning, because it may guide decisions on land utilization in such a way that the resources of the environment are optimally used and that a sustained land management is achieved.

Land suitability classification is an approach in land evaluation that concerns the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. FAO [3] proposed a general classification for the land suitability in which two suitability orders were discerned: suitable (S) and unsuitable (N). The order S was subdivided into a very suitable (S_1), moderately suitable (S_2) and marginally suitable class (S_3). The order N was subdivided into a currently unsuitable (N_1) and permanently unsuitable class (N_2). Although FAO defined principles for evaluation, no specific methodology was suggested to achieve the classification. In recent years, a number of methodologies have been developed under the FAO framework. However, these methods are based on either land characteristics or land qualities and result in a qualitative evaluation. The suitability classes are defined as discrete groupings, separated by strict class definitions or fixed class limits. Land units that have a degree of suitability somewhat intermediate between classes can however only be classified in one single suitability class. A new methodology is developed, based on fuzzy set theory, which gives additional information on the neighbouring suitability class.

The land suitability classification using fuzzy set theory is performed in four successive steps. These steps involve the determination of the membership functions (for each characteristic and for each suitability class membership functions express the degree to which a value of a land characteristic belongs to a suitability class), the determination of the membership values (for a given land unit, the membership values for the different land characteristics and suitability classes are subsequent arranged in a fuzzy relation from land characteristics to suitability classes), the establishment of a weight matrix (land characteristics have a relative importance with regard to different objects under consideration) and the calculation of the evaluation matrix (the suitability class for the considered land unit coincides with the element of the matrix that has the highest value). For the related details, the reader is referred to the joint research work [11].

4 Concluding remarks

This paper reviews in brief some recent applications of fuzzy set theory in nuclear science. Further it clearly indicates the possibilities of the use of fuzzy set theory in nuclear science with the potential advantages of simple calculation for lower cost, intuitive understandability and flexibility.

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