SYSTEMS TO SUPPORT DECISIONS FOR URBAN AREAS

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Keywords: Population growth, population migration patterns,urbanization,regional and urban planning, sustainable development of coastal areas,decision support systems, geographic information systems,constrained cellular automata.

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Summary

This article deals with the methodology of decision analysis and related decision-making models for environmental impact assessment (EIA) of public projects in the urban area and also for risk management for catastrophic risks such as big earthquakes. In EIA we propose to include the assessment of the preferences of the regional inhabitants in addition to the assessment of physical/biological effect of each pollution. For assessing the preference of the regional inhabitants we take into account the complex interdependence, called convex dependence, among multiple attributes when we construct a multi-attribute disutility function.

By using a multi-attribute disutility function we can evaluate the effectiveness of various countermeasures for preventing the environmental impact of a particular project. We also propose to include a consensus formation process among conflicting multiple agents such as regional inhabitants and the enterprise (developer) of the project concerned. For this purpose we construct a group disutility function for two conflicting agents, taking into account the convex dependence between them. This is called the multi-agent utility theory. By using such a group disutility function, we can model the mutual concessions of the two conflicting agents, and hence, we can expect fairer MADM (multiple agents decision-making) for realizing better social welfare. It is shown that a value function under risk is useful to model low probability high consequence events like big earthquakes in the sense that it is a suitable approach to modeling behavioral legitimacy of decision-making for such events.

1. Introduction

Regional and global environmental problems have been raised as borderless problems among many countries, and how to realize "sustainable development" has become an important matter for development without destruction of our common future (WCED, 1987).

This article attempts to show the central idea and results of decision analysis and related decision-making models without mathematical details. Utility theory and value theory are described for modeling value perceptions of a decision-maker under various situations in relation to decision problems for urban areas such as environmental impact assessment and catastrophic risk management.

2. Environmental Impact Assessment and Multi-attribute Impact Theory

Currently, environmental impact assessment (EIA) systems for a so-called large public project, to construct a freeway, an international airport, etc., environmental standards for each environmental quality, such as air pollution, noise, etc., are established separately, and it is assessed whether or not each standard is satisfied by the project enterpriser (developer). Then an attempt is made to realize an appropriate countermeasure for preserving the environmental quality. However, the countermeasure for preserving noise may cause an increase in the air pollution levels of some areas, or it may cause landscape obstruction. Therefore, not only is each environmental quality assessed separately, but the complex influences of multiple environmental items are also to be assessed, in order to preserve a better environment as a total system.

From the methodology point of view multi-attribute utility theory is a powerful tool for multi-objective decision analysis, since it provides an efficient method of identifying the von Neumann-Morgenstern utility functions of a decision-maker. The book by Keeney and Raiffa (1993) describes in detail the standard approach. The significant advantage of the multi-attribute utility theory is that it can handle both uncertainty and multiple conflicting objectives: the uncertainty is handled by assessing the decision-maker's attitude towards risk, and the conflicting objectives are handled by making the utility function multidimensional (multi-attribute). In many situations, it is practically impossible to assess directly a multi-attribute utility function, so it is necessary to develop conditions that reduce the dimensionality of the functions that are required to be assessed. These conditions restrict the form of a multi-attribute utility function to a decomposition theorem.

One of the main objectives of the EIA system is to support decision-making on selecting an appropriate countermeasure from many alternatives. The procedure is summarized as follows:

- **Step 1.** Multiple alternatives of countermeasures are selected and multiple attributes are selected for evaluating the multiple alternatives.
- **Step 2.** A unit of each attribute is clarified and the probability distribution of the consequences is assessed when we choose each alternative.
- **Step 3.** The best and worst level of each attribute is clarified.
- **Step 4.** A multi-attribute disutility function of the regional inhabitants is assessed.
- **Step 5.** Multiple alternatives of countermeasures are evaluated.

In Step 1 conflict often exists among the multiple attributes (vector) x. A representative of the regional inhabitants, who is a decision-maker (DM) in our problem, has his own utility function, $u(x)$, implicitly. We could regard that the DM chooses an alternative based on this utility function. Hereafter, as in Step 4, we deal with a disutility function $d(d=1-u)$, instead of a utility function u, since every environmental item evaluated here denotes the negative utility of the regional inhabitants. Generally, since we can normalize u, whose value lies in [0,1], for negative utility, a disutility function d can also be normalized where $d = 1$ for the worst case and $d = 0$ for the best case.

2.1. Expected Utility Hypothesis

Let $A = \{a, b, \ldots\}$ be a set of alternative countermeasures from which the DM must choose one. Suppose the choice $a \in A$ results in a consequence x_i with probability p_i, and the choice $b \in A$ results in a consequence x_i with probability q_i, and so forth. Let $X = \{x_1, x_2, \ldots\}$ be a set of all possible consequences, where the consequence x_i implies that "the concentration of NO_2 is obtained as x_i" For example, the concentration of NO_2 is one of the most important attributes in the EIA of road traffic. In this case $p_i \geq 0$, $q_i \geq 0$, $\forall_i$, and

$$\sum_i p_i \sum_i q_i = \ldots = 1.$$

Let a real function d be a disutility function on X. Then, the expected disutilities of the alternatives a, b, … are written, respectively, as

$$E_a = \sum_i p_i d(x_i), \quad E_b = \sum_i q_i d(x_i), \ldots \tag{1}$$

The assertion that the DM chooses an alternative that minimizes his/her expected disutility is called the expected utility hypothesis of von Neumann and Morgenstern (1953). In other words, DM chooses an alternative according to the normative rule

$$a \succ b \Leftrightarrow E_a < E_b \quad \text{and} \quad a \sim b \Leftrightarrow E_a = E_b \tag{2}$$

where "$a \succ b$" denotes "a is preferred to b," and "$a \sim b$" denotes "a is indifferent to b." This rule is called the expected utility rule. A disutility function which satisfies Eqs. (1) and (2) is uniquely obtained within the class of positive linear transformations.

2.2. Single Attribute Disutility Function

As shown in Figure 1, let $l_a, l_b, \ldots$ denote lotteries that the DM comes across when he/she chooses the alternative $a, b, \ldots$, respectively. An amount x^c, such that the DM is indifferent between the alternative a and the outcome x^c, is called a certainty equivalent of lottery l_a. From the expected utility hypothesis we obtain

$$d(x^c) = E_a = \sum_i p_i d(x_i) \tag{3}$$

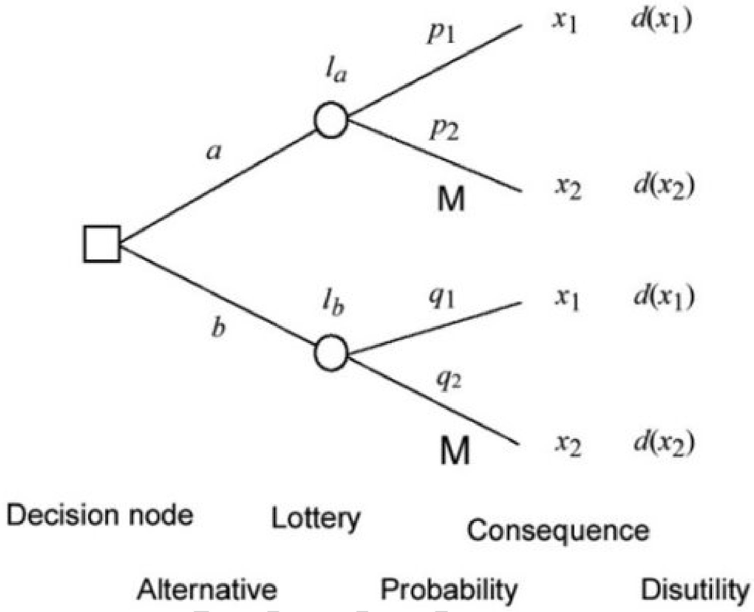

Figure 1. Decision tree and lottery.

In a set X of all possible consequences, let x^0 and x^* be the worst and the best consequences, respectively. Since the disutility function is unique within the class of positive linear transformation, let us normalize the disutility function as

$$d(x^0) = 1, \quad d(x^*) = 0$$

Let $<x^0, p, x^*>$ be a lottery yielding consequences x^0 and x^* with probabilities p and $(1-p)$, respectively. In particular, when $p = 0.5$ this lottery is called the fifty-fifty lottery and is denoted as $<x^0, x^*>$. Let x be a certainty equivalent of the lottery $<x^0, p, x^*>$, that is,

$$x \sim < x^0, p, x^* > \tag{4}$$

Then

$$d(x) = p d(x^0) + (1-p) d(x^*) = p \tag{5}$$

It is easy to identify a single-attribute disutility function of a DM by asking the DM about the certainty equivalents of some fifty-fifty lotteries (Keeney and Raiffa, 1993). By means of a curve fitting technique, like the least-square method, a single attribute disutility function $d(x)$ can be identified. There exists a probability equivalent method in which the probability p is asked of the DM for various levels of x according to Eq. (4).

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Biographical Sketch

Hiroyuki Tamura received the BS and MS degrees in engineering from Osaka University, Osaka, Japan, in 1962 and 1964, respectively, the MS degree in engineering-economic systems from Stanford University, Stanford, California, in 1968, and the Ph.D. degree in engineering from Osaka University in 1971. From 1964 to 1971, he was a Research Engineer with the Central Research Laboratory, Mitsubishi Electric Corporation, Amagasaki, Japan. During this period he received Stanford Graduate Fellowship and Fulbright travel grant, and spent the years 1966 to 1968 at the Department of Engineering-Economic Systems, Stanford University. From 1971 to 1987, he was an Associate Professor, and from 1987 to 1993 he was a Professor with the Department of Precision Engineering, Faculty of Engineering, Osaka University. During this period he spent 1972 to 1973 at the Control and Systems Group, Cambridge University, Cambridge, U.K., as a Visiting Researcher and received a British Council Scholarship. From 1993 to 1997 he was a Professor with the Department of Systems Engineering, Faculty of Engineering Science, Osaka University. Since 1997 he has been a Professor of Systems Science with the Department of Systems and Human Science, Graduate School of Engineering Science, Osaka University. His research interests center on the systems planning methodology for large-scale systems such as modeling, control and decision-making, and their applications to manufacturing systems and public systems. Dr. Tamura was awarded the Paper Prize from the Society of the Instrument and Control Engineers (SICE) of Japan in 1976 and in 1999, Sawaragi Memorial Paper Award in 1990 and the Paper Award in 2000 from the Institute of Systems, Control and Information Engineers (ISCIE) of Japan in 1990, and the Case Study Prize from the Operations Research Society of Japan (ORSJ) in 1991. He is a fellow of Operations Research Society of Japan, senior member of IEEE, member of INFORMS, SRA, SICE of Japan, ISCIE of Japan, etc.