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Abstract

This paper proposes a method to solve qualitative locational choice problems using fuzzy decision tables as matching model. Firstly, the technique of crisp decision tables is explained, and their use in locational choice is advocated. Subsequently, fuzzy extensions of decision tables are defined. Next, using a brief example, it is shown that fuzzy decision tables can be used efficiently for evaluating business locational problems. The proposed method is supported by PROLOGA. This is an interactive rule based design tool for decision table construction, optimization and manipulation.

1 Introduction

Researchers have always been interested in trying to model the locational choice problem of businesses. Usually, this decision-making process involves the construction of a quantitative model. In recent years, however, qualitative techniques (e.g., decision plan nets and decision tables) have been successfully applied as an alternative to the quantitative approaches [11], [18].

In order to deal with imprecision and vagueness, the use of fuzzy set theory to tackle locational choice problems in quantitative modelling has received some attention in the literature [1], [2], [3], [6]. In these studies, different techniques are being suggested such as fuzzy linear programming, fuzzy parametric analysis, and fuzzy simulation. In the area of qualitative locational decision models, however, the application of fuzzy techniques is to our knowledge rather limited [10], [12]. Therefore, in this contribution, we would like to advance the qualitative technique of fuzzy decision tables as an interesting alternative to model locational choice problems.

The paper is organized as follows. In section 2 the crisp decision table representation is briefly described. Section 3 elaborates on how decision tables can be used as a matching model. In this present context, matching is viewed as a two-way process based on functional equivalence. Section 4 of this paper concentrates on the extension of the crisp decision table to include fuzziness. This results in the definition of a fuzzy decision table. Next, an example is given which demonstrates the approach in business locational choice. In section 6, we elaborate on how to use and consult a fuzzy decision table, and discuss the kind of decision output it produces. Finally, our major findings are summarized, and some suggestions for future research paths are given.

2 Crisp Decision Tables

A decision table contains four parts: condition subjects, condition states, action subjects and action values. These four parts can be defined more formally:

Definition 1. Let CS_i be a condition subject with domain CD_i (i = 1, ..., cnum), CT_i be a set of condition states S_{ik} (k = 1, ..., n_i , i = 1, ..., cnum) with S_{ik} being a logic expression, AS_j (j=1..anum) be an action subject; and AV_j = {true (x), false (-), nil (.)} be an action value set (j = 1, ... , anum), then a decision table is a function from $CT_1 \times CT_2 \times ... \times CT_{cnum}$ to $AV_1 \times AV_2 \times ... \times AV_{anum}$ such that each possible condition combination is mapped into one (completeness or exhaustivity) and only one (exclusivity) action configuration. ■

Notably, the elements of CD_i involved in a condition state S_{ik} determine a subset of CD_i, such that the set of all these subsets constitutes a partition of CD_i.

The use of decision tables has several advantages. Firstly, they can be easily verified and validated (V&V) [15]. Subsequently, they provide a structuring formalism which can be used efficiently in the knowledge acquisition phase [13]. Finally, decision tables can be executed very efficiently [7]. A major problem of the use of decision tables, however, is the complexity of the manual building process. Therefore, **PROLOGA** (PROcedural LOGic Analyzer) has been developed, an interactive design tool for computer-supported construction and manipulation of decision tables [14]. When building decision tables, the designer essentially provides the system with the following information: a list of conditions with their states, a list of actions and a list of rules. This will enable the system to construct the corresponding decision tables. During this process, a V&V check will take place [17]. After this check, the decision tables can be consulted. This can be accomplished either visually or by transforming the decision tables to a format that can be executed in an expert system shell or program [13].

3 Decision Tables as Matching Model

Decision tables model choice behaviour on the basis of "end-means" relationships. According to the functional view [11], establishing such a relationship has everything to do with a matching or classification problem. Applied to the locational choice problem of businesses, this classification problem involves making an assessment of the relational match between the characteristics of a potential production environment (i.e., a locational profile) and the characteristics of the production requirements put forward by a particular firm (i.e., an organizational profile). Only when both properties or profiles match successfully, the production environment is able to fulfil the function of potential location site for the firm, and can be classified accordingly. In all likelihood, more than one production environment will be categorized as suitable location site. Therefore, the result of the matching process is a set of functional equivalent production environments from which a final selection can be made. Thus, matching is defined as a two-way process based on functional equivalence, and a knowledge representation formalism, like decision tables, complies with that definition.

On the one hand, a two-way matching process signifies, in our business location example, that a successful match can be achieved either by fitting the characteristics of a production region to the imposed requirements put forward by the firm, or by matching the firm's requirements to the imposed regional conditions. As such, the production environment as well as the individual firm may function as driving-force behind the matching process. Applied to a decision table model, two-way matching entails the specification of two types of input tables: i.e., characteristics of the production environment (supply-side) and characteristics of the firm (demand-side). These two input decision tables are than combined to form an output decision table. The latter table represents the quality of the relational match. On the other hand, functional equivalence refers to the property that production environments, although having quite different locational profiles, are classified as functional equivalent location sites because they comply with the firm's specific locational requirements. In decision table terminology, functional equivalence appears when different combinations of condition states lead to an identical action state.

4 Fuzzy Extensions to Decision Tables

In many real time problems crisp decision tables prove to be too stringent. Therefore, we have enhanced the decision table formalism with some fuzzy concepts. Recent progress in crisp decision table formulation and standardization [13], [15], [16], [17] provides a sound basis on which fuzzy extensions can be made to deal with imprecise and vague decision situations [4], [5].

A crisp decision table may be extended to include fuzziness in the condition part and/or in the action part, which then gives rise to the notion of a fuzzy decision table. Fuzziness in the condition part can be expressed by fuzzy conditions (in form of simple predicates) such as "Distance is *about average*" while fuzziness in the action part can be expressed by linguistic terms such as "Value of land is *high*". In a fuzzy decision table, these linguistic terms and fuzzy sets appear with condition states (S_{ik}) and/or with action subjects (AS_j). More formally, a fuzzy decision table is defined as follows:

Definition 2. Let CS_i be a condition subject with domain CD_i (i = 1, ..., cnum), CT_i be a set of condition states S_{ik} (k = 1, ..., n_i , i = 1, ..., cnum) with S_{ik} being a fuzzy logic expression, AS_j be an action subject incorporated with linguistic terms and fuzzy sets, and AV_j = {true (x), false (-), nil (.)} be an action value set (j = 1, ... , anum), then a fuzzy decision table is a function from CT_1 x CT_2 x ... x CT_{cnum} to AV_1 x AV_2 x ... x AV_{anum} such that each possible condition combination is mapped into one action configuration. ■

An example of a fuzzy decision table, in the field of job application, is shown in Figure 1. This fuzzy decision table was built with the decision table workbench PROLOGA. The construction of fuzzy decision tables can proceed mainly according to the steps of the crisp case, however, some extensions are needed. For example, extra steps are necessary to specify fuzzy sets involved in condition or actions, some provisions are needed to handle fuzzy decision rules, etc.

1. Study	Y				N		
2. IQ test	Fail	Pass or High pass			Fail or Pass	High pass	
3. Language test	-	Fail	Pass	High pass	-	Fail	Pass or High pass
1. Accept	-	-	-	x	-	-	-
2. Refuse	x	x	-	-	x	x	-
3. Further research	-	-	x	-	-	-	x
	1	2	3	4	5	6	7

Figure 1 A fuzzy decision table

As far as the properties of decision tables (i.e., completeness, exclusivity, correctness) are concerned, it can be seen that definition 2 guarantees the completeness because any possible condition combination will lead to a decision in terms of action configurations. The property of exclusivity, however, needs to be relaxed since it is no longer the case that there exists one and only one perfect match. In the fuzzy case, the degree of matching between a column in a decision table and a given condition configuration is a value in [0,1]. This, however, should not be a problem since the nature of fuzziness allows for some overlap between states. This does not mean that the V & V process becomes obsolete in fuzzy systems [8], [9]. The notion of correctness can be determined in a similar way to that of the crisp case. That is, it can be checked by the knowledge engineer whether the fuzzy decision table reflects the ideas of the expert.

5 Fuzzy Decision Tables and Locational Choice

To illustrate how fuzzy decision tables can represent a two-way matching process based on functional equivalence in the field of locational choice, we refer to Figure 2. In this figure, three fuzzy decision tables (i.e., one output table and two input tables) are combined in order to evaluate the labour market conditions (L.M.C.) of a potential location site for a particular business. The output table (i.e., the top table) represents the quality of the two-way relational match. This table is constructed on the basis of the outcome of the two input tables. Note that different categories of matching are possible, and that it is only when the required L.M.C. equals the available L.M.C. that we have a perfect match. Consequently, (strong) over performance or (strong) under performance results from a discrepancy in the required L.M.C. demanded by a particular company, and the available L.M.C. present at a particular location site.

Note, however, that a decision cannot be taken by merely checking with each column of the table to match perfectly a given condition configuration. Instead, the degree of matching between the given condition combination and each column should be evaluated [4]. As a result, more than one action configuration may be chosen, each with a degree in [0,1].

1. ^required L.M.C	low			medium			high		
2. ^available L.M.C	low	medium	high	low	medium	high	low	medium	high
1. strong under performance	.	.	.	.	.	.	x	.	.
2. under performance	.	.	.	x	.	.	.	x	.
3. perfect match	x	.	.	.	x	.	.	.	x
4. over performance	.	x	.	.	.	x	.	.	.
5. strong over performance	.	.	x	.	.	.	.	.	.

1. skilled labour	Y					N
2. unionization rate	< 30 %			>= 30 %		-
3. productivity rate	low	medium	high	low or medium	high	-
1. required L.M.C is low	x	.	.	.	.	x
2. required L.M.C is medium	.	x	.	x	.	.
3. required L.M.C is high	.	.	x	.	x	.

1. educational training	low	medium or high			
2. productivity rate	-	low		high	
3. wage rate	-	< $ 25000	>= $ 25000	< $ 25000	>= $ 25000
1. available L.M.C is low	x	.	x	.	.
2. available L.M.C. is medium	.	x	.	.	x
3. available L.M.C. is high	.	.	.	x	.

Figure 2 Example of two-way matching of labour market conditions

Obviously, to bring our business location problem more in line with reality other location factors need to be evaluated. These include such factors like transportation conditions, production, agglomeration economies, availability of public utilities, etc. For these locational factors, however, an identical matching process can be applied.

6 Fuzzy Consultation

Consulting a fuzzy decision table will automatically lead to decision-making. Before being able to proceed to fuzzy consultation, three additional steps need to be taken:

1. calculation of membership values of condition states;
2. calculation of membership values of action states;
3. determination of the degree of matching.

First, the various membership function values for the different fuzzy condition states have to be calculated. These real numbers, $\mu_A(u)$, represent the grade of membership of u in A; with u being an input variable, and A denoting a fuzzy condition state.

The second step involves an assessment of the membership values of the action states on the basis of the calculated membership values of the different condition states. By definition, an action state in a decision table results from a conjunction of different condition states. In a fuzzy decision table, these condition categorizations are defined as fuzzy sets. Therefore, by applying the fuzzy intersection operator, being the equivalent of the logical AND-operation, membership values are found for the various action states. The intersection operator is one of the standard non-compensatory Zadeh operators that is supported by taking the minimum of the membership functions of the intersected sets. In addition to the intersection operator, the membership values of the action states can also be calculated in case a compensatory operator should be used. A compensatory operator has the property to tend to compensate for the strict minimum typical of applying the Zadeh intersection operator. Usually, compensation can be achieved by means of a simple algebraic transformation at membership value level (e.g., by taking the product of the fuzzy sets involved).

The third and final step deals with establishing the overall degree of matching. This will eventually lead to the fuzzy decision output. Unlike in the crisp case, in a fuzzy environment, more than one action configuration may be chosen, each with a degree in the interval [0,1]. In other words, action states, being also fuzzy sets, overlap each other. This complies with working with multidimensional fuzzy rules.

When comparing the crisp and fuzzy decision output, it should be clear that the latter allows for a more subtle decision differentiation than the former. This is because crisp decision tables are unable to make comparisons between location sites that point to an identical crisp action state. The table evaluates all these locations as functionally equivalent, but makes no further distinction in terms of a degree of matching or ranking order. Recall that it was exactly this lack of flexibility typical of working with crisp decision tables that gave cause to the introduction of fuzziness in the decision-making process.

In contrast to the crisp decision table output, the fuzzy decision table produces for each potential location site a membership value with the fuzzy set of suitable locations. In other words, the matching process will by no means always be evaluated as "ideal". As a result, it is possible to compare and rank location sites in terms of their overall calculated membership values whereby it is obvious that the higher the membership value, the better the degree of matching, and vice versa. Note also that only those locations that have similar membership values are deemed totally functional equivalent.

In conclusion, it may appear that the construction and consultation of a fuzzy decision table is a rather time-consuming process because all decision rules of the crisp decision table need to be specified in terms of membership functions and values. This is however wrong. After all, whenever a zero membership value is calculated for a particular condition state, this implies that all subsequent condition states need not to be determined as they will have no influence on the fuzzy decision output.

7 Conclusions and Future Research

In this paper, fuzzy decision tables were defined and constructed. Moreover, it was explained how the technique can be applied in the field of locational choice modelling. It was also shown that fuzzy decision tables can be used as valuable alternative to other qualitative approaches. As a result, we are currently using fuzzy decision tables to model a locational choice problem of a petrochemical industrial plant.

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