AGRICULTURE KNOWLEDGE MODELLING BY MEANS OF FUZZY DECISION TABLES*

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Basic principles of decision-making using fuzzy decision tables (FDTs) are explained and demonstrated in this paper. The starting point is the crisp decision table formalism and its inability to deal with imprecision and vagueness. It is evident that crisp decision tables produce crisp decision outputs. A modelling technique known as FDTs is presented as a potential solution based on the fuzzy set theory. Properties of FDTs are formally described. Various definitions of fuzzy intersections are used for fuzzy connectives modelling. An impact on the decision process of various types of fuzzy logics is studied.

crisp decision tables; fuzzy decision tables; fuzzy decision making; fuzzy knowledge; fuzzy logic

INTRODUCTION

In agriculture practice there exists quite a big number of activities with fuzzy behaviour. The corresponding fuzzy knowledge should be modelled appropriately. Fuzzy decision tables can be used for the agriculture knowledge presentation as well. Such a presentation holds the following benefits of the classical decision tables:

- check for the completeness,
- check for the consistency,
- redundancy elimination.

Generally, decision table is one of the powerful techniques used for knowledge codification. Decision tables are a useful way to represent logical conditions in a compact form. This format is also easily readable and editable by non-technical users. Decision tables are used to describe and analyze decision situations, where the state of several conditions determines the execution of a set of actions.

MATERIAL AND METHODS

Decision tables typically consist of the following parts, as in example is shown in Table 1.

The table header contains the name of the decision table. The condition stub describes conditions or factors that will affect the decision. They are listed in the upper section of the decision table. Each condition corresponds to a variable, whose possible values are listed among the condition alternatives. Condition entries are Y or N. They express the status of each condition. The action stub contains consequent actions. They are listed in the lower section of the decision table. The number of conditions determines the number of rules that are required to provide an analysis of all the possible combination of conditions. The rules inside decision tables are executed one-by-one in the order they are placed in the table. Each action is a procedure or operation possible to be performed and the entries specify whether the action is to be performed for the set of condition alternatives the entry corresponds to. A possible useful generalization of the action stub is to indicate not only whether the individual action has been executed but also the order of the execution of the selected actions. The order of action can be often important in the agriculture applications. Therefore it can be useful to replaced the X marks by natural numbers 1, … , *N*. This numbers indicate the order in which appropriate actions have been applied.

Crisp decision tables use simple TRUE/FALSE values to represent the condition of alternative choice (like if-then-else). Other types of tables may use numbered alternatives (like case-switch). The execution logic of one rule is the following:

Table 1. Basic form of the decision table

TABLE HEADER		Rules							
Condition stub:		1	2	3	4	5	6	7	8
	condition 1	Y	Y	Y	Y	N	N	N	N
	condition 2	Y	Y	N	N	Y	Y	N	N
	condition 3	Y	N	Y	N	Y	N	Y	N
Action stub:	action 1	X		X		X	X		X
	action 2		X	X	X			X	X

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IF ALL conditions are satisfied THEN execute ALL actions.

Problem of a crisp decision table lies in fact that some conditions cannot be expressed in a way that only binary answer YES/NO is allowed. In the case when the attribute cannot be measured exactly or if the measure value is close to the limit, the answer can be given with the certain vagueness. If the user in such a situation is forced to incline to the binary YES/NO answer, the recommended sequence of actions can lead to the non-success or failure. In this case the YES/NO answer can be substituted by a membership function to a fuzzy set. In this case fuzzy logic or probabilistic representations for conditions shall be used. The user should be informed about fuzziness rate, which has to be taken into account during the application of procedure recommended by decision table. For this purpose the fuzzy decision tables are more appropriate. In these tables the binary YES/NO answer for conditions are replaced by a membership function to fuzzy set of the respective action sequence.

The fuzzy decision table (FDT) can be described as follows (see Vanthienen, Wets, 1995; Guoqing Chen et al., 1995). FDT consists of a condition stub and an action stub, each stub allowing fuzziness to be represented. More formally:

FDT (form 1): Let CS_i be a condition subject with domain CD_i ($i = 1, \dots, cnum$), CT_i be a set of condition states S_{ik} ($k = 1, \dots, n_i$, $i = 1, \dots, cnum$) 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 ($j = 1, \dots, anum$), then a fuzzy decision table (FDT) is a function from the set $CT_1 \times CT_2 \times \dots \times CT_{cnum}$ into the set $AV_1 \times AV_2 \times \dots \times AV_{anum}$ such that each possible condition combination is mapped into one action configuration.

Moreover, in a FDT, when all the decision rules involving fuzziness are of the form: "If *X* is *A* then *Y* is *B*", the FDT can now be (equivalently) expressed in a form where *Y* is an action subject and *B* is one of the action subject values. In this case, the value of AS_j ($j = 1,2, \dots, anum$) will be not only true (X) or false (–), but also a fuzzy set or a linguistic term. Thus we have another form of FDTs:

FDT (form 2): Let CS_i be a condition subject with domain CD_i ($i = 1, \dots, cnum$), CT_i be a set of condition states S_{ik} ($k = 1, \dots, n_i$, $i = 1, \dots, cnum$) with S_{ik} being a fuzzy logic expression, AS_j being an action subject, and $AV_j = \{av \mid av$ is a fuzzy subset of $AS_j\}$ be an action value set ($j = 1, \dots, anum$), then a fuzzy decision table (FDT) is a function from $CT_1 \times CT_2 \dots \times CT_{cnum}$ to $AV_1 \times AV_2 \times \dots \times AV_{anum}$ such that each possible condition combination is mapped into one action configuration.

The second form seems to be more convenient for our purpose because the YES, NO, NIL configuration of action is replaced by the fuzzy logic linguistic terms. Therefore we cannot express actions order by a simple modification. This order can be very important in agriculture applications. On the other hand, because all fuzzy logic expressions can be presented in a tautologically equivalent form in disjunctive conjunctive normal form, it is not necessary to talk about fuzzy logic expressions in the table. The fuzzy sets are fully sufficient to express the condition states. This consideration leads to the following more simple modification of the FDT definition.

Recommended modification of FDT definition: Let CS_i be a condition subject with domain CD_i ($i = 1, \dots, c_{num}$), CT_i be a set of condition states S_{ik} ($k = 1, \dots, n_i$, $i = 1, \dots, c_{num}$) with S_{ik} being a fuzzy set characteristic function (the fuzzy logic variable or its negation), AS_j be an action subject incorporated with linguistic terms and fuzzy sets, and $AV_j = \{1, 2, \dots, a_{num}$, FALSE ≡ –, NIL ≡ .$\}$ be an action value set ($j = 1, \dots, a_{num}$), then a FDT is a function from $CT_1 \times CT_2 \times \dots \times CT_{c_{num}}$ into $AV_1 \times AV_2 \times \dots \times AV_{a_{num}}$ such that each possible condition combination is mapped onto one action configuration.

The numbers $1, 2, \dots, k \le a_{num}$ indicate a YES answer for the respective action simultaneously with the order of its execution.

RESULTS AND DISCUSSION

Beekeeping represents a problem area with quite a number of decision situations where conditional attributes are often not crisp and unambiguous. This ambiguity can cause, that advised actions may bring risk of financial loss of further beekeeping. In these cases it is appropriate to use the fuzzy logic and using fuzzy decision tables for such knowledge representation. Analogous situation in other agriculture activities can occur.

Let us present the following simple example from apicultural area: REQUEENING INTO COLONY. Requeening presents the problem of adding a queen (mother-bee) to colony. This action depends on the season, time of the queenless and inherence of the laying worker in the colony. The following knowledge may be defined based on this:

If it is the early spring, then requeening into colony is relatively easy. In this example it can be requeening into colony by a cage. If it is early spring and time of the queenless is short, then requeening into colony without the cage. If interval of the queenless time is long, then the requeening is complicate. If laying worker in the colony, then requeening is too complicated, requeening by means of the ethyl alcohol. In all those cases it is necessary to remove the queen cells. The expression of respective knowledge using the crisp decision table can have the following form – Table 2.

The respective fuzzy decision table represented by linguistic terms can be following – Table 3.

Table 2. Representation of knowledge described above using the crisp decision table

Requeening INTO COLONY	RULE							
Early spring?	**Y**				**N**			
Queenless time is short?	**Y**		**N**		**Y**		**N**	
Laying worker in the colony?	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**
Remove the queen cells		1		1		1		1
Requeening standard realization by means of cage		2						2
Direct requeening into colony				2		2		
Requeening is complicated, ethyl alcohol utilization is necessary	1		1		1		1	

Table 3. Representation of knowledge described above using the fuzzy decision table

Requeening INTO COLONY	RULE								
Laying worker in the colony?	**Y**	**N**							
Appropriate time?	–	**Y**				**N**			
Short queenless time?	–	**Y**		**N**		**Y**		**N**	
Vast colony?	–	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**
Remove the queen cells		1	1	1	1	1	1	1	1
Requeening is easy – requeening direct		2	2						
Requeening by means of cage				2	2		2		
Add the brood frames						2	3		
Fortify the colony			3		3		4		2
Requeening with ethyl alcohol	1							2	3

The representation using membership function:

The fuzzy set for "appropriate time" is for example defined by the membership function (Fig. 1).

The fuzzy set for "short queenless time" is for example defined by the membership function (Fig. 2).

The fuzzy set for "colony size" is for example defined by the membership function (Fig. 3).

Let us consider for example the following model situation: *The requeening with laying worker not present in the colony, on 5th of April, with the queenless time 10 days, for the colony of 13 frames.* If we use a standard fuzzy negation for conditions defined as

$$(\underset{\bullet}{\neg} f)(x) = 1 - f(x),$$

we have the following description of the case situation – Table 4.

For computing the weights in each column we have to use various type of fuzzy conjunctions denoted by the common symbol $\underset{\bullet}{\wedge}$.

$$A \underset{\bullet}{\wedge} Q \underset{\bullet}{\wedge} S.$$

Various fuzzy logic conjunctions can be used for this purpose. Most popular are the following three variants of conjunction:

1. Standard (also Gödel's, Zadeh's) conjunction defined as

$$(f \underset{S}{\wedge} g)(x) = \min(f(x), g(x)).$$

2. Algebraic product (also probability or Goguen's) conjunction defined as

$$(f \underset{P}{\wedge} g)(x) = f(x) \cdot g(x).$$

3. Lukasewicz's (also Giles's) conjunction defined as

$$(f \underset{L}{\wedge} g)(x) = \max(f(x) + g(x) - 1, 0).$$

We shall obtain the following results for various fuzzy conjunction types (Table 5).

CONCLUSION

From the table presented above it is clear, that usage of various fuzzy logic conjunctions leads to different estimations of weights for recommended actions. The choice of appropriate fuzzy logic depends on several factors. First, the risk of the improper action choice compared to the passivity has to be considered. In the agriculture practice there are many situations where higher care (connected with financial needs) against a risk of health or environment damages must be considered. However, sometimes also passivity can be a great risk.

Standard fuzzy logic is the most optimistic for the weight of the action recommended. This weight is equal the weight of the most weak condition for this action. The sum of weights of all recommendations using standard fuzzy logic can be greater then one.

Algebraic fuzzy logic corresponds to the situation when the conditions are mutually independent. It means addition of probability of independent events. If the decision table is complete, the sum of weights of all recommendations shall be equal to one.

Lukasewitz's fuzzy logic is rather pessimistic. The sum of weights for the action can be lower then one. The

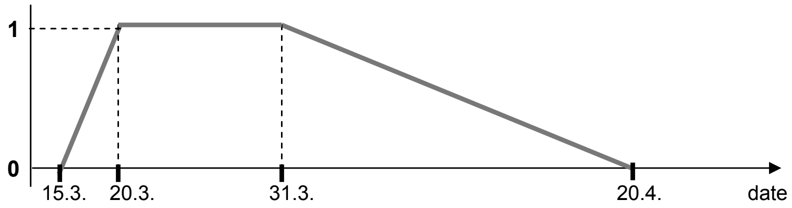

Fig. 1. Membership function for the fuzzy set ”appropriate time”

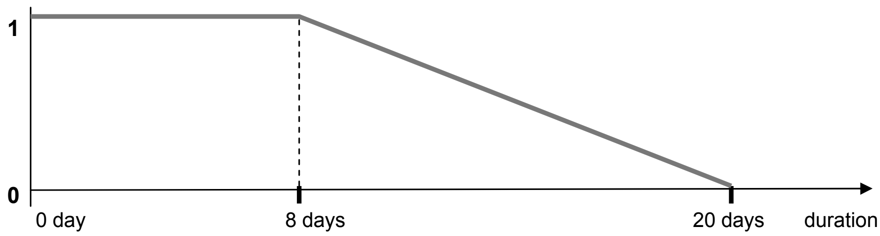

Fig. 2. Membership function for the fuzzy set “short queenless time”

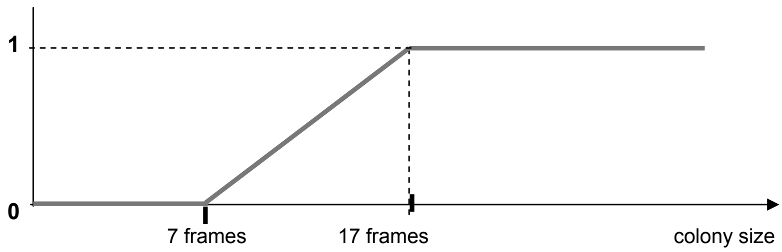

Fig. 3. Membership function for the fuzzy set “colony size”

Table 4. FDT for the model situation above

Requeening INTO COLONY	RULE								
Laying worker in the colony?	**Y**	**A**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
Appropriate time? (A)	–	0.75	0.75	0.75	0.75	0.25	0.25	0.25	0.25
Short queenless time? (Q)	–	0.8	0.8	0.2	0.2	0.8	0.8	0.2	0.2
Vast colony? (S)	–	0.6	0.4	0.6	0.4	0.6	0.4	0.6	0.4
Remove the queen cells		1	1	1	1	1	1	1	1
Direct requeening		2	2						
Requeening by means of cage				2	2		2		
Add the brood frames						3	3		
Fortify the colony			3		3		4		3
Requeening with ethyl alcohol	1							3	4

Table 5. FDT for the situation above with membership function values for suggested actions

Requeening INTO COLONY	RULE								
Laying worker in the colony?	Y	N	N	N	N	N	N	N	N
Appropriate time? (*A*)	–	0.75	0.75	0.75	0.75	0.25	0.25	0.25	0.25
Short queenless time? (*Q*)	–	0.8	0.8	0.2	0.2	0.8	0.8	0.2	0.2
Vast colony? (*S*)	–	0.6	0.4	0.6	0.4	0.6	0.4	0.6	0.4
Remove the queen cells		1	1	1	1	1	1	1	1
Direct requeening		2	2						
Requeening by means of cage				2	2		2		
Add the brood frames						3	3		
Fortify the colony			3		3		4		3
Requeening with ethyl alcohol	1							3	4
Standard $\wedge_S$	1	0.60	0.40	0.20	0.20	0.25	0.25	0.20	0.20
Algebraic product $\wedge_P$	1	0.36	0.24	0.09	0.07	0.08	0.12	0.03	0.02
Lukasewicz’s $\wedge_L$	1	0.15	0	0	0	0	0	0	0

usage of this fuzzy logic can be recommended in the case of a high risk resulting from improper action and a low risk from passivity.

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Modelování zemědělských znalostí pomocí fuzzy rozhodovacích tabulek.

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Článek popisuje a demonstruje základní principy rozhodování pomocí fuzzy rozhodovacích tabulek. Tento nástroj vychází z formalismu ostrých rozhodovacích tabulek, neumožňuje však zpracovávat nepřesné a mlhavé znalosti. Ostré rozhodovací tabulky vedou k ostrým závěrům, což není vhodné pro mnoho zemědělských aplikací. V zemědělské praxi existuje celá řada aktivit vyznačujících se fuzzy průběhem. Z těchto důvodů je v článku navrženo možné řešení této situace založené na teorii fuzzy množin, fuzzy logiky a modelovací techniky, známé jako fuzzy rozhodovací tabulky (FDT).

Autoři navrhují vlastní variantu FDT přijatelnou pro reprezentaci nepřesných znalostí z oblasti zemědělské praxe. Vlastnosti této podoby FDT jsou formálně popsány. Pro fuzzy konjunkci a fuzzy implikaci, odpovídající různým typům definice průniku fuzzy množin, je diskutován vliv na rozhodovací proces a váhu navržených postupů.

Užití fuzzy rozhodovacích tabulek je ilustrováno na příkladu z včelařské praxe v situaci nepříznivého stavu včelstva, který je způsoben nepřítomností včelí královny. Podmínky tohoto problémového stavu jsou velmi často nejednoznačné (mlhavé) a případná doporučená opatření jsou spojena s určitým rizikem ohrožení dalšího kvalitního rozvoje včelstva. Navíc tento stav může být komplikován různými možnými kombinacemi dotyčných podmínek, které způsobují obtížnost hledání příslušných opatření. V praxi pak méně zkušený včelař často hledá pomoc či konzultaci u odborníků. Případný expertní systém by tuto situaci zjednodušil svojí dostupností a pohotovostí. Nejpracnější záležitostí bude proces získávání odpovídajících znalostí pro naplnění jeho báze znalostí. V této oblasti již klasické rozhodovací tabulky v nedávné minulosti zcela prokázaly svoje přednosti, které usnadňují tvorbu znalostních bází. Jde především o srozumitelnost, přehlednost, eliminaci redundance a kontrolu kompletnosti reprezentovaných znalostí.

Obecně rozhodovací tabulky představují užitečný způsob reprezentace znalostí v kompaktní a snadno čitelné podobě. FDT tyto přednosti přebírají a v řadě případů i rozšiřují. Ve znalostním inženýrství se používají dvě varianty FDT, z nichž první dovoluje reprezentovat fuzzy podmínky a druhá fuzzy závěry (doporučení). Ostré podmínky a fuzzy podmínky lze kombinovat. Jednotlivé sloupečky pak představují jednotlivá pravidla, která lze velmi snadno plnit do odpovídající báze znalostí. Váha míry splnění daných podmínek pak určuje váhu, s kterou lze doporučit příslušný postup. Srozumitelnost a čitelnost usnadňuje komunikaci mezi expertem a znalostním inženýrem a omezí případná nedorozumění při specifikování znalostí.

Odlišnost přístupu navrženého v článku od dosud publikovaných fuzzy zobecnění rozhodovacích tabulek spočívá v tom, že výsledkem může být doporučení několika možných alternativních postupů, každého s příslušnou vahou takového doporučení. Uživatel je tak informován, že možné řešení jeho problému nemusí být jednoznačné. Počet doporučení a jejich váha záleží na volbě definice fuzzy průniku množin, která určuje váhu konjunkce podmínek příslušného doporučení. Tato volba může být přizpůsobena zhodnocení rizika plynoucího z chybného opatření v porovnání s rizikem hrozícím z nečinnosti.

Závěry, které tento článek vyvozuje, jsou použitelné i v dalších obdobných zemědělských aktivitách, které jsou rovněž poznamenány neurčitostí a mírou rizika zvolených opatření či postupů.

ostré rozhodovací tabulky; fuzzy rozhodovací tabulky; fuzzy znalost; fuzzy rozhodování; fuzzy logika

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