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Data, Information and Knowledge in Agricultural Decision-Making

M. Houšková Beránková, M. Houška

Czech University of Life Sciences Prague, Faculty of Economics and Management, Department of Systems Engineering

Abstract

It is very important to work with data, information and knowledge correctly, when a decision model is used as a support for managerial decision-making. Unfortunately, these terms are understood differently in various branches; particularly, the definitions of knowledge are very different. It causes problems in praxis; it is not clear, in which case data processing, information or knowledge/expert systems are appropriate to use.

In this paper we introduce modern approaches to indentifying these terms. The objective of the paper is to identify data, information and knowledge in decision-making process, particularly in multiple-criteria decision-making model, to help users of such models to better understand it. To reach this objective, we need to provide appropriate definitions of data, information and knowledge as well as the specific algorithms of decision-making models used in the following sections. Then we go through the decision-making process and analyze the needs of data, information and knowledge in its individual phases. We demonstrate our approach on grains dryer selection problem under conditions of a specific agriculture company.

Key words

Data, Information, Knowledge, Multiple-Criteria Decision-Making Model, Grain Dryers.

Anotace

V rozhodovacích modelech je správná práce s daty, informacemi a znalostmi velmi důležitá. V různých oborech jsou však tyto termíny chápány odlišným způsobem a zejména definice termínu znalost jsou velice různé. V praxi to může působit problémy, neboť nemusí být zřejmé, kdy je vhodné použít systémy pro zpracování dat, v jakých případech informační systémy a kdy znalostní/expertní systémy.

Článek představuje moderní přístupy k identifikaci těchto pojmů. Jeho cílem je identifikovat data, informace a znalosti v rozhodovacím procesu, konkrétně v modelu vícekriteriálního rozhodování, což pomůže uživatelům ke správné konstrukci těchto modelů. Pro dosažení tohoto cíle nejprve uvádíme vhodné definice těchto pojmů a konkrétní algoritmy vícekriteriálního rozhodování, se kterými budeme dále pracovat. Potom projdeme standardní rozhodovací proces a analyzujeme potřebu dat, informací a znalostí v jeho jednotlivých fázích. Náš přístup demonstrujeme na problému o výběru sušičky zrnin, který je řešen v podmínkách konkrétního zemědělského podniku.

Klíčová slova

Data, informace, znalosti, vícekriteriální rozhodování, sušičky zrnin.

Introduction

Terms “data”, “information” and “knowledge” are frequently used, but with different meaning in different theories. It is hard for scientists or any other experts from different fields to communicate with each other, when they understand these basic terms differently. Communication barrier can happen not because of special terms in communication, but because of generally used terms definition. Mathematical models can be very useful for many experts in their work, but they do not use them – they do not understand them well and do not know how to fill them by data and which information and knowledge they have to use to get some valuable results.

Many authors deal with decision-making support in agriculture regarding to data, information and knowledge available. Šporčič et al. (2010) provides an overview of models which take into consideration simultaneously several criteria, so that they can provide more comprehensive measures of management, and to serve as a background for planning and decision making in agriculture and forestry. They stress that an appropriate method must be chosen in a way in which all the data available with the reasonable amount of effort and dedication could be utilized as fully as possible. They demonstrate that multiple-criteria decision making models in forestry, as in other business systems, can be very strong support to planning and decision making.

Ascough et al. (2009) use decision-making models to solve a tillage system selection problem. They point out that this decision has significant implications for the farm enterprise, both economically and environmentally. Reduced tillage or no-tillage are considered to be conservation tillage practices that assist in maintaining acceptable environmental goals at potentially lower economic costs; however, the decision to invest in conservation tillage systems also involves risk. The authors use the SMART risk analysis framework enriched by other analytical techniques (SERF analysis, the probability of target value or Stop Light approach) to compare individual tillage scenarios and select the best one for specific conditions.

Recio et al. (2003) deal with the complexity of a farm planning process. They mention that traditional approaches to this process have been very simple and unable to manage the complexity of the problem, which involves scheduling of field tasks, investment analysis, machinery selection, cost/benefit analysis, and other aspect of the agricultural production process. The authors stress the necessity to work with available information and knowledge in appropriate way and for this purpose they develop a new approach to the planning process for medium-large farms and integrated in a more general framework to build decision support systems in agriculture.

The objective of this paper is to identify parts of multiple-criteria decision-making model as data, information and knowledge to help users of such models to better understanding it. To reach this objective, we need to provide appropriate definitions of data, information and knowledge as well as the specific algorithms of decision-making models used in the following sections. Then we go through the decision-making process and analyze the needs of data, information and knowledge in its individual phases.

We demonstrate our approach on one of the most used methodology for problem solving in agriculture: machinery/equipment selection problem solved by multiple-criteria decision-making model (see e.g. Bonneau, M., Dourmadi, Lebret et al. (2008) or Gomez-Limon, Arriaza and Riesgo (2003)). In particular we solve grains dryer selection problem under conditions of a specific agriculture company.

Material and methods

Data, information and knowledge

Interesting characterization of data (and information) provide Havlíček and Pelikán (2007). In their work, data is characterized as a set of facts, measures and statistics about real entities that are possible to be named. If data is expressed by selected one-dimensional measure that describes or identifies quantitative characteristic of the object, it is represented by a scalar number. In case of two or more objects the vector of numbers is used.

Firstly, they formalize assignment the name to an object by measure of the zero order as follows

d0(x) = name,

where

x is an entity and

name is a language element.

Then, one-dimensional measure determines assessment of some object's property and can be interpreted as a distance of the property rate from the beginning of measuring scale.

Formally,

d1(x, p) = k,

where

x is assessed property of object

p is the beginning of measurement and

k is real constant, language term or other assessment kind that express object's property evaluation.

The above given relationship can be read as follows:

"Functional value d of the one-dimensional measure of the selected property of the object x related to the beginning of measure scale p is equal to k."

Information is represented by data and their meaning. It depends on aggregation of data into context. According to Choo (2001), the observer makes sense of noticed data through a process of cognitive structuring which assigns meaning and significance to perceived facts and messages. What meanings are constructed depends on the schemas and mental models of the actor. Schemas mediate between sensory experience and intellectual though: "Schema refers to an active organization of past reactions, or past experience, which must be always supposed to be operating in any well-adapted organic response."

Information is ordered or processed data that – given into connections and context – decrease the entropy of a system. It is of no use to repeat here the theory of information, Shannon's concept of entropy and related things. The most important aspect that allows us to measure and work with information is that information has its standard and respected unit: a bit.

One bit volume information is included in a statement that leads to uncertainty decreasing. The statement is referring to a specific event with probability of occurrence $p = 0.5$.

From the viewpoint of measures (Havlíček, Pelikán, 2007), information is described by two-dimensional measure. The measure expresses relationships between two objects, elements, entities. It could be formalized as follows:

$d2(x_i , x_j) = f(k_i , k_j) = d_{ij}$,

where

x_i a x_j are compared properties of objects,

k_i a k_j are their values and

d_{ij} is result of their comparison expressed as a decision "yes" (true, valid, …) or "no" (false, invalid, …). The result can be expressed by such language term or by Boolean number.

Information is typically represented by table, by graph or by single variable function. In such case we suppose that all connections between data are valid if it is not explicitly said vice-versa. The above given relationship can be read as follows:

"Relationship between two object's properties xi and xj respectively between values of these properties ki and kj is equal to Boolean value that determines validity of the assignment."

There are many definitions of knowledge based on various approaches. It has been a central matter of human studies especially in philosophy. The knowledge, the process of cognition, the question of know ability of world, has been an object of investigation from time out of mind. The crucial change came when the knowledge became an important economical power and source of economical advance and competitiveness.

Nonaka and Takeuchi (1995), defined knowledge as "a dynamic human process of justifying personal belief in face of factual reality" and described three main observations on knowledge:

- Knowledge, unlike information, is about beliefs and commitments. Knowledge is a function of a particular stance, perspective or intention.
- Knowledge, unlike information, is about action.
- Knowledge, like information, is about meaning.

The problem oriented definition of knowledge was formulated by Havlíček (2006): "Knowledge is information which is used to solve successfully a problem and can be shared with others to solve or facilitate the solution of similar problems."

Such a definition tends to distinguish knowledge according to its owner. This outlines the issue of private versus public knowledge. The defenders of private ownership of knowledge affirm that knowledge represents the main source of competition advantage of the companies. New knowledge should be protected otherwise there will be no motivation for investments into research. Other opinions state that knowledge is not a degradable resource but it increases in repeated applications (Wierbicki, Nakamori, 2007).

The prevailing attitude towards the ownership of knowledge is that knowledge must be a (global) public asset. From the economical point of view this means that knowledge should lack the characteristics otherwise typical for economic assets, namely rivalry and excludability. That some forms of knowledge are public goods is least likely the case for additional, that is, new knowledge. And it is additional knowledge that turns to profit (Stehr, 2007).

Knowledge is defined as an ordered set of information in space and time about important notions, data, facts, axioms, laws, and inference rules related to a specified field of human experience, embedded in a given thought-framework (Roska, 2003). It follows that information without a thought-framework will not be qualified as knowledge.

Atomic (elementary) piece of knowledge is sometimes called “knowledge unit”. Similarly to the term “knowledge” it also has a lot of characteristics and more or less an exact definition. For example, Zack (1999) says that “a knowledge unit is an atomic packet of knowledge content that can be labeled, indexed, stored, retrieved and manipulated”. There are many such clear definitions in specialized literature.

That is why in the following text the term of “elementary knowledge” will be used equivalently for expressing and representing knowledge units based on systems approach. In their work, Dömeová, Houška and Houšková Beránková (2008) discussed the term “elementary” as more suitable for this purpose. It includes and summarizes three important characteristics and approaches to knowledge unit – the knowledge unit is atomic, it is an element of some system, and it is the knowledge of users.

Knowledge unit may be expressed as a whole in natural language. There is no exclusivity; each part of knowledge unit has several facultative ways of expression and almost all of their combinations are feasible.

The basic form of elementary knowledge expression derived by systems approach is defined as follows: “If you want to solve the elementary problem Y in the problem situation X to reach the objective Z, then apply the solution Q“.

Multiple-Criteria Decision Model

Multiple-criteria decision-making (MCDM) model consist of several parts.

- decision alternatives,
- criteria,
- criteria matrix and
- criteria weights.

Decision alternatives are given by a finite set of feasible solutions that includes m alternatives. Such alternatives are evaluated by criteria; the model includes n criteria in general. Usual objective of the MCDM model is to find the alternative with best overall evaluation subject to all criteria (optimum, or rather compromise alternative). Alternate objectives could be to obtain complete order of alternatives or to split the set of alternatives to “efficient” and “inefficient” alternatives. As soon as the evaluation of alternatives subject to all criteria is known, criteria matrix can be constructed. Criteria matrix is formalized as

$Y = (y_{ij})$,

where

i is the index of the alternative,

j is the index of the criteria and

y_{ij} is evaluation of the i-th alternative subject to the j-th criterion.

Not only quantitative evaluation is required in the criteria matrix. For more general case of the criteria matrix, the term of “matrix of alternative attributes” could be equivalently used. Its general matrix form is as follows:

$$\mathbf{Y} = \begin{array}{c} \\ a_1 \\ a_2 \\ \vdots \\ a_m \end{array} \begin{array}{c} \begin{array}{cccc} f_1 & f_2 & \cdots & f_n \end{array} \\ \begin{pmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{12} & \cdots & y_{1n} \\ \cdots & \cdots & \cdots & \cdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{pmatrix} \end{array}$$

In our case study, we use two specific MCDM methods: the Saaty’s method for criteria weights assessment and the Weighted Sum Approach to select the compromise alternative.

Saaty’s method is a way to formalize experts’ judgments on the importance of compared objects (Saaty, 1980). It is based on pairwise comparison, i.e. each element is compared with all others. Technically, the comparison is being done in Saaty's matrix that is squared and reciprocal. The following standard scale is used for preference evaluation:

1 - the importance of the i-th and j-th elements is equal;

3 - the i-th element is weakly preferred against the j-th;

5 - the i-th element is strongly preferred against the j-th;

7 - the i-th element is very strongly preferred against the j-th;

9 - the i-th element is absolutely preferred against the j-th.

The final importance of each element is then calculated as normalized geometric mean of the row of the Saaty's matrix.

Weighted Sum Approach is the most frequently used method based on the utility function principle (Hwang and Yoon, 1981). In this method, the decision matrix is normalized by a linear utility function; a normalized criteria matrix R = (r_{ij}) is calculated as

$$r_{ij} = \frac{a_{ij} - D_j}{H_j - D_j},$$

where Dj is the negative-ideal value of the criterion j and Hj is the ideal value of the criterion j. Then, a total utility provided by the i-th alternative is calculated as

$$u_i = \sum_{j=1}^{n} r_{ij} v_j,$$

where v is the vector of normalized weights. Complete order of alternatives is determined by descending values of the total utility function.

Results and Discussion

Let us go through the complete multiple-criteria decision-making process in an agricultural company to identify how data, information and knowledge are supporting it.

Step 1: Objective setting

The process cannot start without a precise determination of the decision-making objective. It should stem from the description of the problem situation and make a base for the selection of criteria. In this phase, all data, information and knowledge are necessary to be used. The decision-maker needs data about the current situation in the company, information about the purpose of the decision-making, and, of course, deep professional knowledge of the substance of the decision-making object. No wonder that Simon (1960) calls this phase Intelligence and sees it as the most important as well as the most complicated and most creative part of the decision-making process.

Step 2: Criteria selection

In concordance with a typical hierarchical structure of the MCDM problems (Saaty, 1980), criteria should be derived from the decision-making objective and on the same base, they should be evaluated by weights. In this phase, in which the model is designed, the decision-maker works with data (names of the criteria) and information (criteria weights). For instance, we can have criterion f1 or f2 (data) and say that criterion f1 has the weight value v1 = 0.11 or the criterion f2 has the weight value 0.42 (information). There is no professional knowledge, only the algorithmical one to use a method for the estimation of the complete weight vector.

Step 3: Evaluation of alternatives subject to the criteria

This is the most illustrative example how to distinguish data and information in decision-making model. Remember the matrix form of the MCDM model from Material and Methods. While headers of the rows and columns of the model (alternative and criteria names/acronyms/symbols) are one-dimensional and so they have the quality of data, interior elements in the criteria matrix are double-indexed. They naturally express the relationship between two objects (evaluate each individual alternative subject to each individual criterion) and so they have quality of information. No professional knowledge is required except expert evaluation of qualitative criteria.

Step 4: Selection of the compromise alternative

This is usual mechanical task for a specific algorithm of the MCDM models. The role of the decision-maker is usually passive; his work is finished by a precise configuration of the model. We can only discuss about the quality of results. Formally, it is information to say e.g. “Alternative 1 has total utility equal to 0.77” or “The rank of the alternative 2 is 3”. In fact, it could also have the quality of knowledge, because the final evaluation of alternatives concentrates all objective of the problem, specific configuration of the model (criteria selection and their weights) as well as the evaluation of alternatives subject to the criteria and the algorithm for the selection of the compromise alternative. Pragmatically, as the result of the decision-making process, we can formulate a knowledge unit as follows:

When we solve the particular MCDM problem in the specific situation of the company to select the best alternative, we should select the compromise one.

This statement has surely the quality of knowledge.

Example

Now we demonstrate our approach on a real decision-making problem in Unesovsky statek, a.s. An analyst should recommend to the management one of four variants of a new grain conditioner to replace the old and inappropriate one.

For our purposes, we follow the process of the analysis and identify necessary data, information and knowledge in each step. Background story and all data are taken from the study Stupka (2011), all calculations are own.

It is crucial to pay attention to post-harvesting treatment of grains, because it directly influences their quality. After harvested, the grains should be dried immediately, because it improves measurable biochemical characteristics, which have positive impact on total financial profit from the grains. Usual capacity of dryers is between 6 and 75 tons of dried grains per hour; for the purposes of the company, the appropriate capacity is about 20-40 tons/hour.

So, the objective of the decision-making task is to select the best continuous grain conditioner. First we should identify individual components of the decision-making model and the MCDM model, respectively.

List of alternatives:

a1 - Matthews Company MC-975 Grain Dryer;

a2 - Continuous Grain Dryer S 420 E;

a3 - Alvan Blanch DF 30000;

a4 - Continuous Grain Dryer NDT 7-1.

The variants are compared subject to the following criteria:

f1 - Performance of drying from 19 to 15% of humidity ($t.h^{-1}$);

f2 - Fuel consumption ($m^3.t^{-1}$);

f3 - Air recirculation (%);

f4 - Total costs (EUR);

f5 - Availability of service (hours).

Now we can construct the criteria matrix for this problem:

We can analyze the contents of the criteria matrix from the viewpoint of the occurrence of data, information and knowledge. We can identify data; they are in headers of rows and columns, e.g. “alternative a3” or “criterion f1”. Information is inside the criteria matrix, in each individual cell of the matrix. For instance, the value y11 = 21.8 can be read as “alternative a1 is evaluated by the criterion f1 with value 21.8” or in particular “the

	f1	f2	f3	f4	f5
a1	21.8	1	30	92 530	48
a2	40.3	1.81	15	104 440	24
a3	33	1.1	15	140 000	48
a4	20	1.1	0	100 000	48
Criteria type	max	min	max	min	min

Table 1: Criteria matrix for grain dryer selection problem (Stupka, 2011).

grain dryer Matthews Company MC-975 decreases the humidity of 21.8 tons of grains from 19 to 15% in one hour". Criteria type row is also typical instance of information. We can say "the criterion f1 is maximizing" or "the criterion f4 is minimizing". In this phase of decision-making, there is no knowledge.

We continue with the assessment of criteria weights. Using the Saaty's methods (see Saaty, 1980), the criteria weights are calculated as follows:

	f1	f2	f3	f4	f5	R_i	v_i
f1	1	1/2	3	1/5	5	1.08	0.14
f2	2	1	4	1/3	6	1.74	0.23
f3	1/3	1/4	1	1/7	3	0.51	0.07
f4	5	3	7	1	9	3.94	0.52
f5	1/5	1/6	1/3	1/9	1	0.26	0.04

Table 2: Saaty's matrix with weights calculated.

Obviously, we are still working with information. The values in the Saaty's matrix can be interpreted in identical way as in the criteria matrix in the previous case. The final values have also the quality of information; we can say "the weight of the criterion f1 is 0.14".

On the other hand, some knowledge is also required for this phase of decision-making. We need knowledge how to determine exact weights of criteria. Even though the final weights have quality of information, their determination is equal to providing information about such information. As we mentioned in Material and Methods, information about information (meta-information) is one of the specific forms of knowledge.

Finally, we can determine the compromise alternative. For this purpose, one of the most common methods – Weighed Sum Approach – is used. Considering the criteria weights from table 2, the results are as follows:

	Partial utility functions					Total utility	Rank
	f1	f2	f3	f4	f5		
a1	0,09	1,00	1,00	1,00	0,00	0,83	1
a2	1,00	0,00	0,50	0,75	1,00	0,60	3
a3	0,64	0,88	0,50	0,00	0,00	0,33	4
a4	0,00	0,88	0,00	0,84	0,00	0,64	2

Table 3: Final comparison of alternatives.

This phase is fully aimed at working with knowledge. Several kinds of knowledge are necessary for achieving the objectives of model solving:

1. Knowledge of specific MCDM method on the level of algorithm. Simply said how to obtain reliable results from input information.

2. Knowledge of results interpretation. Apparently, the results also have the quality of information, because they provide relationships between individual variants and their utilities. But, alternatives utilities are depended on determined criteria weights and valid for their specified values only. As it was mentioned above, criteria weights are set in concordance with objective of problem solving in some more or less unique problem situation. Using systems approach to knowledge unit definition (Dömeová, Houška a Houšková Beránková, 2008), it is possible to write generally:

When it is necessary to determine the best of individual alternative in the MCDM model solution to make the final decision subject to specific weights values, compare total weighted utility of individual alternatives.

3. Knowledge of sensitivity analysis. Independently on used MCDM method, stability of found solution subject to possible changes in weight vector should be analyzed.

Conclusion

As we showed the role of all data, information and knowledge in agricultural decision making is unsubstitutable. But if we distinguish professional and algorithmical domains, we will see that data and information are included rather in the professional domain than in the algorithmical one; on the other hand, we need professional and algorithmical knowledge approximately in the same ratio to make the decision correctly.

We also showed interesting relativity of data, information and knowledge. Not in an initial phase but in the final one, the same value can be understood in all three ways. For instance, we can understand the maximum value of the total utility function ui as data. Of course, it is a part of one-dimensional measure (a vector) with one index. Or, we can say total utility of the i-th alternative is ui; that statement has surely the quality of information, because it defines the relationship between two objects (alternative and total utility function). Finally, the statement - if you want to choose the compromise alternative, then select the one with the maximum value of the total utility function ui - has the quality of knowledge.

For further research, we see the following perspective way to continue. It is connected with subjective perceiving of these terms in agriculture praxis and its influence on the quality of decision-making. We have already consulted several decision-making processes ex-post, when the decision-making procedure failed. The mathematical model was correct, but the decision-makers undermined the key role of data and information in the intelligence phase and so they omitted one or more important aspects of the task. This cannot repair even the best mathematical model.

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Corresponding author:
Ing. Martina Houšková Beránková, Ph.D.
Department of Systems Engineering
Faculty of Economics and Management
Czech University of Life Sciences Prague
Kamýcká 129
165 21, Prague 6
Czech Republic
tel. +420 224 382 237, berankova@pef.czu.cz

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