ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 328 Number 7, 2013

http://dx.doi.org/10.11118/actaun201361072923

SELECTION OF SCENARIOS IN QUALITATIVE MODELS: THE CASE OF A GOVERNMENT TENDERS MODEL

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Received: August 12, 2013

Abstract

VESELÝ ŠTĚPÁN, DOHNAL MIRKO: *Selection of scenarios in qualitative models: The case of a government tenders model.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 7, pp. 2923–2929

The task of this methodological paper is to clarify the process of selection of scenarios in qualitative models. Articles on qualitative modeling usually do not cover the topic of scenarios selection exhaustively, only the basic operations are (sometimes) described. This lack of detail might lead to confusion and overly simplified understanding of the process of model development when new users meet with qualitative models. We outline the basic principle of consistency, i.e. that scenarios inconsistent with a given knowledge item entered into the qualitative model are discarded from the model. With help of this principle, the vast set of all "imaginable" scenarios (27^{12} in our case) can be reduced to just 7 scenarios in less than 40 steps. A manageable number of scenarios is important to enable interpretation and practical use, e.g. to evaluate concrete tasks and policies. For our demonstration we use our previously published model of government tenders. The current paper can help those who want to understand qualitative models and their development better, it is not restricted to the problem of qualitative modeling of government tenders.

qualitative model, scenarios, consistency, model development, knowledge engineering

1 INTRODUCTION

Formalized qualitative models (e.g. De Kleer and Brown, 1984; Kuipers, 1986, 1989) capture the fundamental features of a system under study, while eliminating quantitative detail. Qualitative modeling can be seen as one of the uncertainty calculi, such as fuzzy sets (Zadeh, 1965), rough sets (Pawlak, 1982) and order of magnitude reasoning (Raiman, 1991). It is based upon an algebra of three values – positive, negative and zero – and thus does not require detailed numerical information about the problem at hand.

Qualitative methodology has been used to model decision making, management and socio-economic problems, see e.g. Benaroch and Dhar (1995), Bohanec *et al.* (1995), Hinkkanen *et al.* (2003), Curic (2008), Luňáček and Martinovičová (2010), Konečný *et al.* (2010), Režňáková *et al.* (2012a, 2012b), as well as complex engineering tasks (e.g. Hurme *et al.*, 1993; Rebolledo, 2005, 2006). For an overview see Bourseau *et al.* (1995), De Jong (2004), Price *et al.* (2006).

The task of the present paper is to clarify the process of selection of scenarios in qualitative models. We will demonstrate how the process works using the model of government tenders decision making from our previous paper, Veselý and Dohnal (2012).

A number of our colleagues, students and/or field experts with whom we have discussed qualitative modeling find it a bit confusing that the more information is entered into the model, the less output in the form of scenarios it usually produces.

This confusion probably stems from a heuristic that the more complexity goes in, the more complexity must go out. This is not, however, how qualitative models work. The jist of the present paper can be summarized by saying that qualitative modeling starts with a large possibility space that contains all imaginable scenarios. And by adding more and more knowledge (e.g. expert knowledge) into the model, the possibility space is gradually constrained and some of the initially "imaginable" scenarios are discarded, because they are not possible according to the input knowledge. Other papers on qualitative modeling usually do not cover the topic of scenarios selection in much detail, only the basic operations are described (e.g. Vícha and Dohnal, 2008a, 2008b).

The paper is organized as follows: Section 2. describes the method of qualitative modeling briefly. Section 3. deals with the problem of scenarios selection.

2 QUALITATIVE MODELS

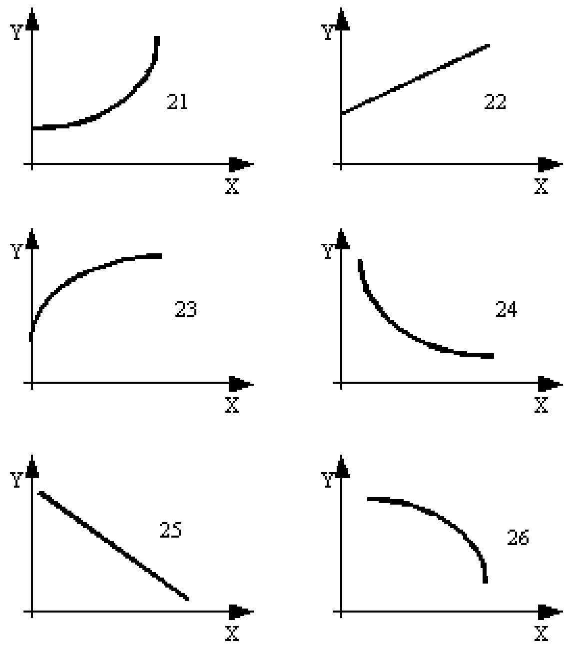
There are only three qualitative values, positive, zero or negative, for details see e.g. Dohnal (1991). A qualitative scenario of a qualitative model is specified if all its *n* qualitative variables $X \equiv (X_1, X_2, \ldots, X_n)$ are described by the qualitative triplets (X, DX, DDX), where DX and DDX are the first qualitative and second qualitative derivatives with respect to time.

Let us suppose that the triplet:

$$(+ + 0) \equiv (P, DP, DDP), \qquad (1)$$

represents price P(t) as a function of time. It means that the price P is positive (P = +). The price is increasing in this example (DP = +) and the increase is linear (DDP = 0), as the second derivative is zero.

Typical examples of qualitative relations are given in Fig. 1. The example given in Eq. (1) is the relation with code no. 22 in Fig. 1, where X would denote time and Y would denote price.



1: *Examples of pair-wise qualitative relations*

The identification numbers given in Fig. 1 are shape codes for the respective qualitative shapes, i.e. for example 21 is a code number for function characterized by positive value of Y and positive first and second qualitative derivatives of Y with respect to X (triplet + + +).

If the second derivative (DXX) is not known then there are two variants of qualitative proportionality:

M_+ If X is increasing then Y is increasing
If X is decreasing then Y is decreasing
(2)
M_– If X is increasing then Y is decreasing
If X is decreasing then Y is increasing.

For the sake of parsimony, only the most important aspects of qualitative models are presented here. More details and examples can be found e.g. in Dohnal (1991), Trave-Massuyes *et al.* (2004) and also in Veselý and Dohnal (2012). However, what we presented in this section should be sufficient to enable clear understanding of what will be outlined in the next section.

3 SELECTION OF QUALITATIVE SCENARIOS

Qualitative scenarios (and qualitative transitions among them, but those are not discussed here) represent a complete description of all possible behaviors within the modeled system. The question to be addressed in this section is: "How do we know that a behavior (a scenario) is possible?" This can be determined based on the knowledge entered into the qualitative model.

First, we have to return to our paper Veselý and Dohnal (2012) to summarize the input knowledge included in our model. This input knowledge is given in the list (3) and especially in Tab I.

Our model describes decision making in government tenders. Based on a literature survey and discussions with a team of experts, the model is characterized by the following set of twelve variables (3). The variables are defined in the original paper.

EPP Efficiency of public purchasing
INV Investors' rating of the government
BIA Biases to favor some offers
COR Corruption
CON Control rules
DIC Contradictions in rules, i.e. level of inconsistencies (3)
EXP Expert arbitrage
COM Complexity of decision problems
INF Availability of relevant information
SUB Subjectivity of judgment
FUZ Criteria fuzziness
COS Monitoring costs.

Subsequently, the qualitative model was represented by the set of relations between variables given in Tab I. This was again based on a literature survey and dialogues with a team of experts (MBA

I: *Qualitative model of government tenders represented by a set of pair-wise relations*

		Variables				Variables	
No.	**Shape**	**X**	**Y**	**No.**	**Shape**	**X**	**Y**
1	21	INV	EFF	21	M_–	COR	CON
2	21	EXP	EFF	22	21	COM	DIC
3	23	INF	EFF	23	24	INF	DIC
4	21	COM	COS	24	23	SUB	DIC
5	M_–	SUB	CON	25	26	BIA	EXP
6	26	COS	EFF	26	23	INF	EXP
7	M_–	DIC	EFF	27	26	FUZ	EXP
8	M_–	COR	EFF	28	26	COR	EXP
9	23	CON	INV	29	24	INF	BIA
10	M_–	DIC	INV	30	M_+	FUZ	BIA
11	21	EXP	INV	31	23	COR	BIA
12	24	BIA	INV	32	M_–	INF	COM
13	26	FUZ	INV	33	26	FUZ	INF
14	26	COR	INV	34	26	COR	INF
15	M_+	BIA	COS	35	M_+	FUZ	SUB
16	24	INF	COS	36	21	COR	SUB
17	21	FUZ	COS	37	23	COR	FUZ
18	23	COR	COS	38	21	DIC	COS
19	26	BIA	CON	39	24	EXP	COS
20	M_–	FUZ	CON				

Note: See Fig. 1 for the respective shapes, such as “21”, “24”. As stated in Eq. (2) M_+ represents positive proportionality and M_– represents negative proportionality.

students at Brno University of Technology with experience with government tenders and the authors of Wouters, 2011 and Režňáková *et al.*, 2012a, 2012b). The qualitative data for the Veselý and Dohnal (2012) study, which we also use here (see Tab. I), were obtained from the experts during years 2011 and 2012.

The literature we reviewed to contribute to and to check the opinions elicited from the experts includes mostly relatively recent papers (the median date of publication is 2004), but also some older ones (for details refer to section 3. in Veselý and Dohnal, 2012). The most useful source of information on government procurement was probably Khan and Schroder (2009).

In Veselý and Dohnal (2012) all pair-wise relations given in Tab. I were entered in the qualitative model at once. This yields 7 possible scenarios (see Tab III in the original article). The question “Why are there just 7 scenarios?” was not addressed in the original paper. But it can be seen as a very pertinent question. Therefore we will try to shed light on this question here, or more generally on the question of scenarios selection.

Scenarios selection can be seen as a consistency problem.

At the beginning of the process of model development, we usually have just a set of variables. Even at this initial stage, it is possible to calculate solutions for the qualitative model. But it would not have any practical value, because we would obtain all “imaginable” scenarios, i.e. all combinations of qualitative values for each triplet.

Remember that in a scenario each variable is represented by a qualitative triplet (X, DX, DDX) – see section 2. In the model of government tenders we have 12 variables, hence 12 triplets in each scenario. Each value (X, DX and DDX) in the triplet can be either +, – or 0. So, at this initial stage, there are $3^3 = 27$ possible combinations for each triplet. Since we have 12 such triplets (one for each variable) in each scenario, there are $27^{12} = 150.094.635.296.999.000$ possible combinations of +, – and 0, where each combination represents one “imaginable” scenario.

This vast number of 27^{12} scenarios needs to be reduced to obtain a practical solution. This is done by including new knowledge into the model. In the last step, all interrelations from Tab. I will be included in the model, which will give us the 7 scenarios from the original paper. But lets have a look at the process at a slower pace.

As a second step of model development, we realized together with our experts that all variables can have only positive values (and values of 0 in some rare cases – but we excluded these cases from the model to keep it simple). For instance, there is always some corruption (in an unlikely scenario there might be zero corruption, but we do not consider such cases). So, at this stage, there are $3^2 = 9$ combinations for each triplet (the value of X – e.g.

the amount of corruption – is always positive, so it does not increase the number of combinations within the triplet). Since we have 12 such triplets (one for each variable) in each scenario, there are 9^{12} = 282.429.536.481 possible combinations, i.e. scenarios *consistent* with the inclusion of the piece of knowledge that states that all variables are positive (this is why we speak of a *consistency* problem).

Obviously, this huge number of 9^{12} still lacks any practical value, but it illustrates how the number of scenarios can be reduced in the qualitative model.

As a third step, we will start entering individual interrelations into the model. Before we show how the number of scenarios is reduced with each entered interrelation (see Tab. III), we will outline the basic principle of how inconsistent scenarios are discarded from the model with the inclusion of knowledge items.

Consider the following simple example. The interrelation No. 5 in Tab. I states that there is a negative relationship between Subjectivity of judgment (SUB) and Control rules (CON, the variables are listed in (3)). All scenarios that violate this relationship must be discarded from the model when this knowledge item is entered. If we had a model with just two variables (CON and SUB), the

II: *Scenarios before and after entering an interrelation*

Model *before* entering interrelation No. 5			**Model *after* entering interrelation No. 5**		
	Variables			**Variables**	
Scenario	**CON**	**SUB**	**Scenario**	**CON**	**SUB**
1	++*	++*			
2	+–*	+–*			
3	+0*	+0*			
4	++*	+0*			
5	+–*	++*	5	+–*	++*
6	+0*	+–*			
7	++*	+–*	7	++*	+–*
8	+–*	+0*			
9	+0*	++*			

Note: All variables are assumed to be positive. For simplicity, third derivatives are not considered in this example, thus the third derivative (DDX) is denoted by * in all triplets (* can mean either +, – or 0).

III: *Number of scenarios dependent on the pair-wise relations entered in the model*

Interrelations entered	Number of scenarios	Interrelations entered	Number of scenarios
None	27^{12}	1-20	27
All variables positive	9^{12}	1-21	27
1	45.328.197.213	1-22	27
1-2	9.685.512.225	1-23	27
1-3	1.248.354.909	1-24	27
1-4	200.353.257	1-25	27
1-5	22.261.473	1-26	27
1-6	3.129.597	1-27	27
1-7	347.733	1-28	27
1-8	38.637	1-29	27
1-9	10.449	1-30	27
1-10	8.019	1-31	27
1-11	8.019	1-32	15
1-12	999	1-33	11
1-13	291	1-34	11
1-14	291	1-35	11
1-15	171	1-36	11
1-16	171	1-37	11
1-17	171	1-38	11
1-18	171	1-39	7
1-19	63		

model solution *before* and *after* entering interrelation No. 5 would look as shown in Tab. II. The solution is intuitively comprehensible: we must simply exclude all scenarios that have other values of second derivatives (DX) than either + for CON *and* – for SUB and/or – for CON *and* + for SUB.

Tab. III indicates the number of scenarios obtained using the basic principle of consistency. The columns "Interrelations entered" give the range of interrelations entered (i.e. 1–3 means that interrelations 1, 2 and 3 from Tab. I were entered into the model).

Using the principle of consistency, the vast number of "imaginable" scenarios (27^{12}) has been rapidly reduced by entering available pieces of knowledge.

As is apparent from Tab. III the solutions of qualitative models become interpretable after including about 20 pair-wise interrelations between variables. This statement is true for models with about the same number of variables we have in our model, more (less) knowledge items need to be entered if the model features more (less) variables.

It can also be observed that entering certain interrelations (e.g. interrelations number 11, 14, 16, 17 and 18 – see Tab. III) does not reduce the number of scenarios obtained. The reason is that the respective set of scenarios before the particular interrelation was entered had already been consistent with that interrelation.

Our approach in Veselý and Dohnal (2012) and in this study is not to concentrate on a specific government tender or on a specific period. Rather, we want to pin down some relatively robust qualitative relations among variables, which can be found in many tenders in recent history (because we use mostly recent literature and recent insights of experts as sources of information).

The approach of collecting information from diverse sources is directly linked to the fact that information about government tenders is often scarce. Therefore pieces of information can not be obtained from a single source, but have to be collected from different sources (such as individual papers or experts with a particular experience) and put together. Such an approach, however, does not enable us to define the precise conditions under which our model holds – because the conditions (e.g. the political situation in the country) were not the same across situations described by particular information sources. As we mentioned in Veselý and Dohnal (2012), many modifications, upgrades and extensions of our model are possible. The way the model is going to be modified by a user depends on the user's theoretical and practical needs. If the user, for example, wants to be sure about the conditions under which the model holds (e.g. a given country in a given election term), he will include in the model only those interrelations from Tab I. (and possibly some additional ones) that are correct for the country and period of interest. However, given the scarcity of data on government procurement, such a restricted model could sometimes offer only a solution with a large number of scenarios, hence with a limited practical value, as we show in this paper.

4 CONCLUSION

Our task was to clarify the process of selection of scenarios in qualitative models. We outlined the basic principle of consistency, i.e. that scenarios inconsistent with a given knowledge item entered into the qualitative model are discarded from that model. With help of this principle, the vast set of all "imaginable" scenarios (27^{12} in our case) was reduced to just 7 scenarios.

This methodological paper can serve as a useful reference for researchers who wish to develop their own qualitative models. It can also be of use to practitioners who would like to better understand the underlying principles, implications and possible limitations of qualitative models relevant for their field of work.

The principles of qualitative modeling described in this paper can be applied in many different areas – not only in modeling government procurement. Some of the areas we mentioned in the introduction are management, economics and engineering; other areas include environmental and investment problems. To conclude, this paper sheds light on the selection of qualitative scenarios, an important aspect of the qualitative modeling technique, and thus makes this technique more accessible to practitioners and researchers in various fields.

SUMMARY

The task of the present paper is to clarify the process of selection of scenarios in qualitative models. Articles on qualitative modeling usually do not cover the topic of scenarios selection exhaustively, only the basic operations are (sometimes) described, see e.g. Vícha and Dohnal, 2008b: Qualitative identification of chaotic systems behaviours. *Chaos, Solitons & Fractals*, *38*, 70–78. This lack of detail might unfortunately lead to confusion and overly simplified understanding of the process of model development when new users meet with qualitative models. We outline the basic principle of consistency, i.e. that scenarios inconsistent with a given knowledge item entered into the qualitative model are discarded from the model. For example, when we know that only positive relationship between two variables is possible, all scenarios with negative relationship between these variables are excluded from the model. With help of this principle, the vast set of all "imaginable" scenarios (27^{12} in our case) can be reduced to just 7 scenarios in less than 40 steps. A manageable number of scenarios

is important to enable interpretation and practical use, e.g. to evaluate concrete tasks and policies. For our demonstration we use our previously published model of government tenders, see Veselý and Dohnal, 2012: Decision making in government tenders: A formalized qualitative model. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *60*, 397–406. The current paper can help those who want to understand qualitative models and their development better, it is not restricted to the problem of qualitative modeling of government tenders.

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