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DECISION MAKING IN GOVERMENT TENDERS: A FORMALIZED QUALITATIVE MODEL

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Abstract

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The paper presents a simple formalized qualitative model of government tenders (GTs). Qualitative models use just three values: Positive/Increasing, Zero/Constant and Negative/Decreasing. Such quantifiers of trends are the least information intensive. Qualitative models can be useful, since GT evaluation often includes such goals as e.g. efficiency of public purchasing, and variables as e.g. availability of relevant information or subjectivity of judgment, that are difficult to quantify. Hence, a significant fraction of available information about GTs is not of numerical nature, e.g. *if availability of relevant information is decreasing then efficiency of public purchasing is decreasing as well.* Such equationless relations are studied in this paper. A qualitative model of the function F(Goals, Variables) is developed. The model has four goal functions, eight variables, and 39 equationless relations. The model is solved and seven solutions, i.e. scenarios are obtained. All qualitative states, including first and second qualitative derivatives with respect to time, of all variables are specified for each scenario. Any unsteady state behavior of the GT model is described by its transitional oriented graph. There are eight possible transitions among seven scenarios. No a priori knowledge of qualitative modeling is required on the reader's part.

government tenders, decision making, multidimensional, scenarios, qualitative model

1 INTRODUCTION

Models and research frameworks of government tenders (GTs) are usually simplified or quite specific, see e.g. Celentani and Ganuza (2002), Mougeot and Naegelen (2005), Auriol (2006), Van Long and Stähler (2009), Pomazalová and Korecki (2011). That is, they include only a few variables (for example Celentani and Ganuza, 2002, include price, quality, corruption and two measures of competitiveness) and/or exclude variables that are difficult to measure (e.g. the influence of informal ground rules, bureaucratic hierarchies, subjective judgment and biased decision making).

These specific, quantitative models and theories of GTs are meaningful, but in reality there are many problems and influences (variables) of different nature related to GTs and some of them are difficult to observe and measure with precision (e.g. corruption – see Treisman, 2000; biases to favor some offers, expert arbitrage – see Khan and Schroder, 2009; compliance to rules – see Edwards and Wolfe, 2005), which makes the development of generally applicable, i.e. multidimensional models difficult. All these problems (multidimensionality, different nature of included variables, and measurement difficulties) are encountered in evaluations of specific, individual GTs, too (e.g. Pongpeng and Liston, 2003). However, in the present study we focus on a more general level of GTs evaluation, i.e. the objective functions and independent variables included into our model are relevant to a broad spectrum of GTs, rather than to any particular GT.

Formalized qualitative modeling is utilized to describe processes and systems (such as GTs) that, because of their complexity, do not allow or render difficult and costly the development of conventional quantitative models in a form of a set of equations followed by a statistical identification of constants, see e.g. Keesman (2011).

The task of the present paper is therefore to outline a multidimensional formalized qualitative model of factors influencing GTs decision making, including some factors that are hard to measure. GTs decision making represents a relatively ill-known, nonlinear and multidimensional system. Such systems are, by their very nature, difficult to observe/measure. One of the main reasons for qualitative GTs model development is therefore information shortage (for instance when only qualitative data are available), see e.g. Hurme *et al.* (1993), Vícha and Dohnal (2008b).

Information shortage can be eliminated by additional information sources including additional observations, which is time consuming and costly, or by utilization of such information items (i.e. qualitative data) which cannot be easily treated by conventional formal tools. For example Khan and Schroder (2009) studied several difficult to measure variables (such as the use of informal decision procedures, compliance to rules, contradictions in rules, and biases to favor some offers) in the context of GTs. Their approach was mostly descriptive in nature, they employed interviews and semantic differential scales.

In this study, we propose a general methodological framework that enables incorporation of many even relatively vague and diverse determinants of GTs decision making.

Qualitative reasoning has been used in some form to model, for instance, complex engineering systems (e.g. Hurme *et al.*, 1993), investment decisions and economic problems (e.g. Benaroch and Dhar, 1995; Hinkkanen *et al.*, 2003; Luňáček and Martinovičová, 2010) and various chaotic systems (Vícha and Dohnal, 2008a, 2008b); see Bourseau *et al.* (1995), De Jong (2004) and Price *et al.* (2006) for an overview.

The paper is organized as follows: Section 2. describes the method of qualitative modeling – the most important properties of qualitative models are defined in subsection 2.1, subsection 2.2 deals with qualitative vector optimization (which is instrumental for development and interpretation of the scenarios presented in subsection 3.2) and subsection 2.3 deals with transition graphs. In section 3. results for the GT model are given and discussed. Section 4. concludes.

2 MATERIALS AND METHODS

2.1 Qualitative models

There are only three qualitative values, positive, zero or negative, for details see e.g. Dohnal (1991), Vícha and Dohnal (2008a). 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:

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

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.

A typical example of a qualitative knowledge item can be formalized by a certain simple relation between two variables X and Y. For example:

If the price (X) of a product is decreasing then the quantity of product demanded (Y) is increasing. (2)

If the price (X) of a product is increasing then the quantity of product demanded (Y) is decreasing, however, the quantity of product demanded (Y) cannot decrease infinitely, it means that a certain positive quantitatively unknown lower limit exists. (3)

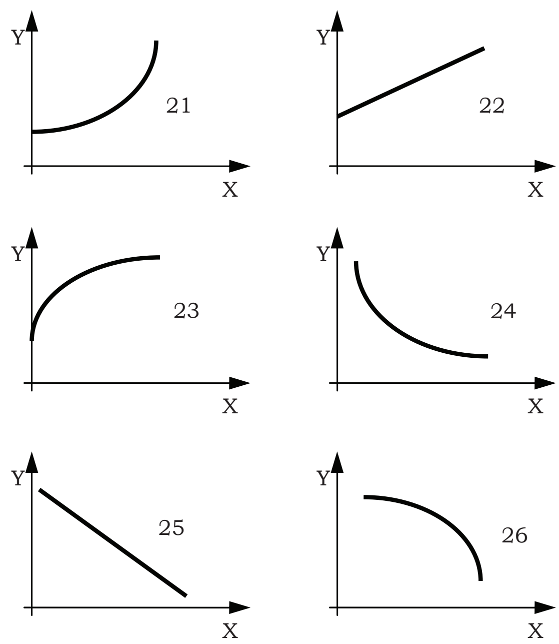
A formal interpretation of the above mentioned qualitative knowledge items (2), (3) is

$$DY/DX = - \quad \text{(see (2))} \quad (4)$$
$$DDY/DDX = + \quad \text{(see (3))},$$

where DY/DX is the first qualitative derivative with respect to X and DDY/DDX is the second derivative. Typical examples of these relations are given in Fig. 1.

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 Y and positive first and second qualitative derivatives of Y with respect to X (triplet +++), and 24 is the code for the relation function (4).

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



1: *Examples of pair-wise qualitative equationless relations*

M_- If X is increasing then Y is increasing
If X is decreasing then Y is decreasing (5)

M_+ If X is increasing then Y is decreasing
If X is decreasing then Y is increasing.

2.2 Qualitative vector optimization

Let us suppose that there are two independent variables X_1, X_2 and two objective functions Q_1, Q_2. For example the first objective function is Profit and the second is Safety. Because of their very nature both objective functions must be maximized:

$$\text{Max } Q_1 \quad \text{Max } Q_2. \tag{6}$$

There is a vector F of constraints represented by a set of equationless relations:

$$F(X_1, X_2, Q_1, Q_2) = 0. \tag{7}$$

Let us presuppose that the unknown qualitative model (7) has the following set of three solutions (scenarios):

Scenario No.	X_1	X_2	Q_1	Q_2	
1	+++	+++	+−−	+−−	
2	++−	+−−	+++	+−−	(8)
3	+−−	+−+	+−+	+++	

Since we want Q_1 and Q_2 to be maximized, see (6), the first qualitative solution, see (8) – scenario no. 1, is highly undesirable, because both objective functions decrease if independent variables X_1 and X_2 follow the qualitative pattern given in scenario no. 1 in (8). Therefore the qualitative behavior of independent variables X_1 and X_2

X_1	X_2	
+++	+++	(9)

is bad with respect to the maximization of two objective functions Q_1 and Q_2 (see (6)).

If there would be a set of scenarios which contain, for example, the following solution

I: *A list of all one dimensional transitions*

No.	From	To	Or	Or	Or	Or	Or	Or
1	+ + +	+ + 0						
2	+ + 0	+ + +	+ + −					
3	+ + −	+ + 0	+ 0 −	+ 0 0				
4	+ 0 +	+ + +						
5	+ 0 0	+ + +	+ − −					
6	+ 0 −	+ − −						
7	+ − +	+ − 0	+ 0 +	+ 0 0	0 − +	0 0 +	0 0 0	0 − 0
8	+ − 0	+ − +	+ − −	0 − 0				
9	+ − −	+ − 0	0 − −	0 − 0				
10	0 + +	+ + 0	+ + −	+ + +				
11	0 + 0	+ + 0	+ + −	+ + +				
12	0 + −	+ + −						
13	0 0 +	+ + +						
14	0 0 0	+ + +	− − −					
15	0 0 −	− − −						
16	0 − +	− − +						
17	0 − 0	− − 0	− − +	− − −				
18	0 − −	− − 0	− − +	− − −				
19	− + +	− + 0	0 + +	0 + 0				
20	− + 0	− + −	− + +	0 + 0				
21	− + −	− + 0	− 0 −	− 0 0	0 + −	0 0 −	0 0 0	0 + 0
22	− 0 +	− + +						
23	− 0 0	− + +	− − −					
24	− 0 −	− − −						
25	− − +	− − 0	− 0 +	− 0 0				
26	− − 0	− − −	− − +					
27	− − −	− − 0						

X_1	X_2	Q_1	Q_2	
++−	+−0	+++	+++	(10)

then the scenario (10) is highly desirable because this scenario maximizes both objective functions in the best possible way, i.e. both second derivatives are positive.

It is not the goal of this paper to study the algorithm how to solve qualitative models, i.e. how the software selects/rejects scenarios. It is a combinatorial problem. The most trivial algorithm is based on systematic confrontation of all possible n-dimensional triplets (e.g. ++−, ++0, +0+) for each variable and the model itself. This type of solution is called brutal force in artificial intelligence. For more details see e.g. Trave-Massuyes *et al.* (2004), Vícha and Dohnal (2008a, 2008b). For details on vector optimization see Jahn (2004).

2.3 Transitions among qualitative scenarios

Any unsteady state behaviors of a system can be described by a time sequence of its scenarios. If each scenario is represented by a node and all transitions are graphically represented by oriented arcs between the corresponding pairs of scenarios, the result is an oriented graph of all possible transitions.

A transitional graph G is an oriented graph. Its nodes are the set of scenarios S and oriented arcs are the transitions T. The set of transitions T can be easily generated by the corresponding set of scenarios S using Tab. I. A complete set of all possible one dimensional transitions is given in Tab. I.

For example the third line of Tab. I indicates that it is possible to transfer the triplet (++−) into the triplet (+0−) (see (1)). This transition is not the only possible. There are two more possible transitions. Namely to (+0−) and to (+00). Tab. I is not a dogma. It could be modified on ad hoc basis. The only requirement is that the transitions must satisfy the common sense reasoning of a user.

3 RESULTS AND DISCUSSION

GT decision making can be characterized by the following set of twelve variables (11), eight independent variables (12) and four objective functions (13).

Objective functions:

EPP Efficiency of Public Purchasing

– see e.g. Talluri and Narasimhan (2003), Lorentziadis (2010)

EPP can be simply defined as the total price the bidder (the government) pays for the procured good or service (with the quality of the purchased good/service hold constant). The higher the price, the lower EPP.

INV Investors' Rating of the Government

– see e.g. Busse and Hefeker (2006), Dassiou and Stern (2009)

INV expresses opinions investors hold about a government's trustworthiness and reliability. For example: is the government trustworthy – if yes, INV goes up. Will the procurement process be fair – if yes, INV goes up. Will the government pay its debts – if yes, INV goes up. There are several methodologies for rating countries and companies. However, INV can also have a form of just a "feeling" an investor has about the government's trustworthiness. Note that trust is vital for maintaining beneficial relationships (e.g. Coleman, 1994).

BIA Biases to Favor Some Offers

– see e.g. Khan and Schroder (2009), Lorentziadis (2010)

Variable BIA indicates the relative proportion of biased decisions (e.g. due to a conflict of interest, bribes and/or erroneous processing) as compared to fair, unbiased decisions. Various measurement methodologies are possible: the proportion of clearly biased and/or dubious individual decisions can be measured, alternatively it is possible to express this variable in monetary terms.

COR Corruption

– see e.g. Celentani and Ganuza (2002), Auriol (2006)

Following Treisman (2000) we define corruption as misuse of public office for private gains. Bribery is typically involved.

(11)

Independent variables:

CON Control Rules

– see e.g. Kovacic (1992), Straub (2009)

Control rules prohibit and regulate certain actions. High values of CON indicate well defined and implemented control rules and therefore good control, low values of CON indicate insufficient control rules and lack of control. Efficient functioning of control mechanisms requires that the supervising agency be independent of the supervised agency (e.g. Stern and Holder, 1999).

DIC Contradictions in Rules, i.e. Level of Inconsistencies

– see e.g. Khan and Schroder (2009)

Procedural and decision rules that prescribe how the procurement process should proceed might be dispersed in several formal (as well as informal) sources. When this is the case, some of the sources might contradict each other (variable DIC increases) – enabling divergent interpretations of what is allowed (recommended) in the GT.

EXP Expert Arbitrage

– see e.g. Khan and Schroder (2009)

Expert arbitrage (EXP) represents the influence of independent expert opinion as compared to political/bureaucratic opinion in the decision process. When expert arbitrage is high, experts can dispute and overrule decisions of politicians/ bureaucrats.

COM Complexity of Decision Problems

– see e.g. Yildrim (2004), Khan and Schroder (2009)

It is well known from psychological and computer science literature that complex problems are more difficult to process than simple problems (e.g. Gorla and Ramakrishnan, 1997). Complex decision problems are characteristic for example by the following features: a) they consist of many partial subproblems; b) these subproblems are interrelated in such a fashion, that it is not possible to solve them in parallel; c) a variety of analytical and decision tools (often requiring special expertise) must be employed to tackle the subproblems. However, a simplified measure of (or rather a proxy for) problem complexity is possible: Tadelis (2012) defines project complexity as how expensive it is to provide a complete set of plans and contingencies.

INF Availability of Relevant Information

– see e.g. Deng *et al.* (2003), Evenett and Hoekman (2005), Fearon (2009)

When there is high INF, important information, such as the criteria and rules for the bidder's decision processes relevant to the particular GT, are available to companies that enter into the tender. Conversely, when INF is low, the competing companies do not possess some of the relevant information (e.g. about the criteria, the decision procedures, deadlines, and/or informal influences – if there are any).

SUB Subjectivity of Judgement

– see e.g. Pongpeng and Liston (2003), Lorentziadis (2010)

Subjective judgment is not based on clearly defined criteria and correct operations with data. Rather, it employs various heuristics (e.g. availability heuristics) to arrive at conclusions and decisions. This typically leads to erroneous judgement and/ or biased choices. Antecedents and consequences of subjective judgement are widely studied in psychological and behavioral economics literature (e.g. Kahneman and Tversky, 1974).

FUZ Criteria Fuzziness

– see e.g. Saen (2006), Lorentziadis (2010)

Highly fuzzy criteria can be interpreted in many ways (e.g. "the company must be experienced in the area"), while crisp criteria usually allow only one or a small number of interpretations.

COS Monitoring Costs

– see e.g. Calvo and Wellisz (1978), Bac (1996)

High monitoring costs mean that relatively many resources are needed to monitor the procurement process (and vice versa for low COS). Among the reasons for high COS are for instance: a) complexity of the GT under observation; b) the monitoring procedures are not well suited for the GT at hand (e.g. they are too detailed, which can lead to unnecesary monitoring steps); c) the monitoring procedures are not sufficiently implemented within

II: *Qualitative model of GTs represented by set of pair-wise relations among variables*

		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				

the monitoring agency, which causes the necessity of expensive ad hoc solutions.

Let us suppose that

$$X \equiv \{CON, DIC, EXP, COM, INF, SUB, FUZ, COS\} \quad (12)$$

is a set of independent variables X and the set Q

$$Q \equiv \{EFF, INV, BIA \text{ and } COR\} \quad (13)$$

is the set of objective functions (see (7)).

3.1 Qualitative model of GTs

The following set of pairwise relations, see Fig. 1, is inspired by the following papers: Greenstein (1993), Mattoo (1996), Auriol (2006), Ahlin and Bose (2007), Khan and Schroder (2009), as well as studies quoted above in (11)) and many dialogues with a team of experts. We consulted the experts about what variables and interrelations to include into the model. They were MBA students at Brno University of Technology with experience with GTs and the authors of Wouters (2011) and Režňáková *et al.* (in press a, b).

The qualitative model is represented by the following set of relations (see Tab. II). See Fig. 1 in section 2.1 for the respective shapes (such as "21", "24"). M_+ represents positive proportinality and M_– represents negative proportionality (see (5)).

The model presented in Tab. II was partially developed by a team of experts. If a consensus was unreachable then the relevant second derivatives were not incorporated and qualitative direct (M_+) and indirect (M_–) proportionalities were used instead.

3.2 SCENARIOS

The set of 7 scenarios – see Tab III – is generated using software described in Vícha and Dohnal (2008a). Different qualitative problems can be easily solved using the set of scenarios which represent a complete description of all possible behaviors.

The scenarios obtained could be interpreted according to the qualitative vector optimization method described in section 2.2. The nature of two of the objective functions (EFF, INV) requires maximization, whereas two other objective functions (BIA, COR) require minimization. Hence, there are two relatively favorable scenarios, scenarios 1 and 2, and two relatively unfavorable ones, scenarios 6 and 7. Scenarios 3–5 are relatively neutral, scenario 3 being preferable to scenario 4, which in turn is better than scenario 5.

For example, since we want EFF and INV to be maximized and BIA and COR to be minimized, scenarios 1 and 2 are highly desirable, because the objective functions Q (see (13)) increase or decrease accordingly if independent variables X (see (12)) follow the qualitative pattern given in those scenarios. As is apparent from Tab. III (scenarios 1, 2), it is necessary to increase control (CON), decrease contradictions in rules (DIC), eliminate fuzzy criteria (FUZ), enable arbitrage of orders from superiors by expert opinions (EXP), reduce the role of subjective judgment in making choices (SUB), reduce the complexity of decision problems (COM) – for example by dividing a tender into several smaller tenders, increase the availability of information (INF) and reduce monitoring costs (COS) to reach a desirable state.

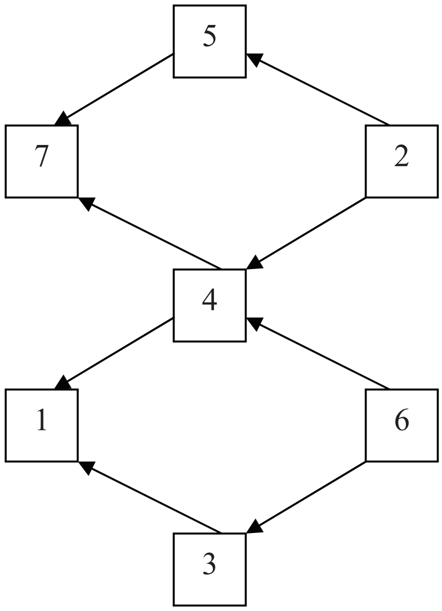
3.3 Possible transitions among scenarios

Additionally, using software described in Vícha and Dohnal (2008a) we were able to determine that it is possible to switch from scenario 2 to scenario 4 or 5, from scenario 3 to scenario 1, from scenario 4 to scenario 1 or 7, from scenario 5 to scenario 7, and from scenario 6 to scenario 3 or 4 (see Fig. 2). The transition rules employed in this analysis are described in section 2.3 and in Vícha and Dohnal (2008b).

An important finding in the analysis of possible transitions is that "favorable" scenario 2 has an inherent danger of degenerating into "neutral" scenarios 4 or 5, where 5 further degenerates into unfavorable scenario 7 (4 can switch to 7, but also to favorable scenario 1). Another important finding is that "unfavorable" scenario 6 tends to move towards favorable scenario 1 via scenarios 3 or 4. Finally, the supposedly "neutral" scenario 5 can switch only to unfavorable scenario 7, which means that policy makers should avoid the states of variables characteristic for scenario 5 (i.e. for example stagnation of monitoring costs, stable complexity of decision problems and stable contradictions in rules

III: *Scenarios*

Scenario	Variables (see (10))											
	EFF	BIA	COR	INV	CON	DIC	FUZ	EXP	SUB	COM	INF	COS
1	+++	+−−	+−−	+++	+++	+−−	+−−	+++	+−−	+−−	+++	+−−
2	++−	+−+	+−+	++−	++−	+−+	+−+	++−	+−+	+−+	++−	+−+
3	+0+	+0−	+0−	+0+	+0+	+0−	+0−	+0+	+0−	+0−	+0+	+0−
4	+00	+00	+00	+00	+00	+00	+00	+00	+00	+00	+00	+00
5	+0−	+0+	+0+	+0−	+0−	+0+	+0+	+0−	+0+	+0+	+0−	+0+
6	+−+	++−	++−	+−+	+−+	++−	++−	+−+	++−	++−	+−+	++−
7	+−−	+++	+++	+−−	+−−	+++	+++	+−−	+++	+++	+−−	+++



2: *A transitional graph of all possible transitions among GT scenarios*

with tendency to *increase* on the one hand, and stable information availability and stagnating arbitrage by expertise with a *declining* tendency on the other hand – see Tab. II).

4 CONCLUSION

Qualitative approach has much to offer when complex and partially vague problems, such as GT decision making, are examined. A qualitative, i.e. information non-intensive, model of factors important for efficient and unbiased GT decision making was outlined. A formal tool for dealing with data of non numerical nature was employed to generate seven possible scenarios and eight possible transitions among them. Desirable and undesirable scenarios and the respective characteristic trends of all included variables were identified. Programs that aim at optimizing GT decision making might use the suggestions offered here profitably.

The present model is definitely not the only alternative. Many modifications, upgrades and extensions are possible. The paper presents just methodology and a simple model as a demonstration.

The main advantages of our qualitative model are:

- No numerical values of constants and parameters are needed.
- The set of possible solutions (scenarios) is complete, i.e. there cannot be any other qualitative scenarios that are not generated by the qualitative model.
- Similar models can be generated using different sets of variables. It is relatively easy to integrate individual models, or to use just a subset of such an integration to build new models, fine-tuned to the practical or theoretical issues at hand.

SUMMARY

The paper presents a simple formalized qualitative model (FQM) of government tenders (GTs). Qualitative models use just three values: Positive/Increasing, Zero/Constant and Negative/Decreasing. Such quantifiers of trends are the least information intensive. Qualitative models can be useful, since GT evaluation often includes such goals as e.g. efficiency of public purchasing, and variables as e.g. availability of relevant information or subjectivity of judgment, that are difficult to quantify. Hence, a significant fraction of available information about GTs is not of numerical nature, e.g. *if availability of relevant information is decreasing then efficiency of public purchasing is decreasing as well*. Such equationless relations are studied in this paper. Another reason for FQM development is that GTs represent a highly multidimensional problem. FQMs are well suited for tackling complex multidimensional tasks, such as GT, since many variables can be included in a FQM. A qualitative model of the function F(Goals, Variables) is developed in this paper. The model has four goal functions, eight variables, and 39 equationless relations. The model is solved and seven solutions, i.e. scenarios are obtained. All qualitative states, including first and second qualitative derivatives with respect to time, of all variables are specified for each scenario. Any unsteady state behavior of GT model is described by its transitional oriented graph. There are eight possible transitions among seven scenarios. The analysis of transitions shows when it is possible to switch from a desirable to an undesirable scenario (and vice versa), which is of importance for decision/policy makers. The main advantages of FQMs are: 1) No numerical values of constants and parameters are needed in the model development. 2) The set of possible solutions (scenarios and transitions) is complete, i.e. there cannot be any other qualitative scenarios that are not generated by the qualitative model. 3) Similar models can be generated using different sets of variables. It is relatively easy to integrate individual models, or to use just a subset of such an integration to build new models, fine-tuned to the practical or theoretical issues at hand. No a priori knowledge of qualitative modeling is required on the reader's part.

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