# A Fuzzy Type-2 Model of IT Governance Concerns

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***Abstract***: IT governance is a topic that has been increasingly discussed since the mid nineties. IT Governance or ICT Governance, is a subset discipline of Corporate Governance focused on information technology (IT) systems and their performance and risk management. However, a shared view on the basic concepts of IT governance is lacking and practitioners do not use present IT governance frameworks to support their decision-making. Now, the definitions of IT governance are broad which in turn implicate difficult and inaccurate assessments. Eventually, IT governance is the preparation for, making of and implementation of IT-related decisions regarding goals, processes, people and technology on a tactical or strategic level. This paper presents a fuzzy type-2 model to understand the relationship among IT Governance concerns, and to assess IT governance complexity. It can be used for a good understanding how the concerns of IT governance behave, how they interact and form the behavior of the whole system. This model is employed to compare how IT governance is defined in practitioners and Cobit.

***Keywords***: Complexity system, Fuzzy type-2 logic, IT Governance concerns.

## 1. Introduction

There are reasonable frameworks and definitions of IT governance, but practitioners within the field do not agree with them and not strictly follow them in their quest for IT governance improvement. This has been stated previously, c.f. (Cumps 2006, Dahlberg 2006), but the different concerns of IT governance between literature, practitioners, and best practice frameworks have not been fully investigated. It has been the belief of the authors that IT governance would be defined differently in literature and by practitioners. Therefore, the IT governance concerns are needed to compare how literature and practitioners define the field. First, the theoretical concerns show that "Strategic," "Monitor," and "People" have been frequently mentioned within many articles. IT governance mainly comprises strategic concerns according to literature. Regarding the decision-making (DM) phases, monitoring of IT related decisions is emphasized. In literature, IT control frameworks and legislations stipulating the need for internal control are often referred. Technology is not the mayor concerns to decide on, and literature rather stresses the importance of establishing roles and responsibilities, and an accountability framework that supports the organization's strive to achieve its business goals. A survey with practitioners is described more thoroughly in Simonsson (2006). The survey was made using a commercial, web-based tool for online surveys. 18 participants responded to the survey. Among these, 72 % primarily had the role of consultants in IT governance change projects, but a few CIOs, security and risk managers, and internal auditors also participated. All respondents claimed previous involvement in at least one IT governance change project, above 80 percent in two such projects or more. According to the practitioners responding the survey, IT governance DM is mainly a strategy issue while tactical decisions are less important. Emphasis is put on understanding the situation at hand prior to making a decision, and solving practical issues regarding how each decision is carried out, such as assigning DM authority, coordinating resources, and aligning IT decision-making with external factors. Monitoring the implementation of decisions already made receives somewhat less attention from the practitioners, according to the survey. Practitioners do however agree that IT decisions are mainly about IT goal setting; strategy development, alignment of IT and business goals, etc. Another important topic is the establishment of a corporate decision-making structure with clear assignment of roles and responsibilities, while IT processes and technology issues are less stressed.

Cobit is a well-known framework for IT governance improvement, risk mitigation and IT value delivery (Ridley 2004, Holm Larsen 2006, Debraceny 2006). A survey with Cobit is described more thoroughly in (Simonsson and Johnson, 2006). Strategy, Monitoring and Processes are received the highest marks. Compared to the concerns identified in literature, it is clearly visible that Cobit is focused on decisions regarding the processes while people receive less attention. Further, Cobit spends more effort in discussing the understand phase and less on the decide phase. Strategic concerns are most often dealt with, while tactical concerns are only briefly discussed. Compared to the practitioners' concerns, Cobit emphasizes processes but lacks hands-on support for decisions regarding people and goal settings. Also, Cobit focuses on decision monitoring to a larger extent than what practitioners do, while the opposite is valid for understand and decide.

Most authors agree on IT governance as a top management concern of controlling IT's strategic impact, and the value delivered to the business c.f. (Weill 2004, ITGI 2005, De Haes 2005, Ribbers 2002). But whether the core of IT governance is a set of structures, processes and relational mechanisms (De Haes 2005), bundled performance metrics to aid IT process monitoring (ITGI 2005) or cascaded Balanced Scorecards (Kaplan 1996, Van Grembergen 2004) is not agreed upon. There is also a gap between what is stated in literature and the opinions of practitioners: The theories developed in literature are not frequently used by consultants or CIOs (Cumps 2006,

Dahlberg 2006). Control Objectives for Information and related Technology, Cobit, is the most renowned framework for support of IT governance concerns (ITGI 2005, Guldentops 2004), but it does not really address the concerns considered important in literature and by practitioners (Simonsson and Johnson, 2006).
The difference between literature, practitioner and Cobit seems to lay in those very interconnections (and interactions) between the concerns of IT governance, and all that they can result in. It is not enough to understand the nature of the "more than one or many concerns" themselves, it's also necessary to understand the exact nature of the interconnections and how they affect the behavior of the whole IT governance. When there are such interconnections and they are "Not simple" and "Difficult," a complexity system can be used. The only consensus on what makes something complex is that the definition of complexity is evolving. IT governance is also a complexity system. But how people apply such terms can vary widely, making it difficult for the rest of us to zero in on the essence of complexity systems. It should come as a relief to know that the experts don't always agree either. In this respect, Lee, Cho and Moon (2010) address really the concerns considered important in literature and by practitioners. They suggest a fuzzy collective behavior model based on IT governance concerns.
The purpose of this paper is to suggest another IT Governance concerns model based on fuzzy type-2 logic, and to represent how the concerns should be really addressed by practitioners and Cobit. This model can be regarded as more realistic version of Lee, Cho and Moon's study. When we go about designing IT Governance structure as a control system, this model will be guiding its organization in view of practitioners. Returning to complex interactions of IT Governance concerns, Practitioners feel a need to attempt relating the system/process to be controlled, the tasks involved in controlling it, the control system, and the context of use. Section II defines IT Governance concerns considered important in literature as a complexity system, and by practitioners neural-network learning as a parameter estimation problem and describes the basic formulation and properties of type-2 fuzzy logic. Section III presents a design process of IT Governance concerns model based on fuzzy type-2 logic. In section IV, it is considered whether and how fuzzy type-2 logic applies to IT governance assessment. Section V reports simulation results comparing the proposed approach with Cobit.

## 2. IT Governance Concerns and Fuzzy Concept

Complex systems typically have some characteristic properties, but the extent to which a particular system exhibits any given property can vary. In this respect, IT governance system includes the fuzzy concepts to a great extent. What makes IT governance complex is the number of decisions that have to be made regarding its design, the number of people or organizations that have to be involved in those decisions, and the fact that they' re probably inconsistent. IT governance has inconsistent objectives, so decisions have to be negotiated. An important consideration is whether a system, such as an enterprise, is planned for by some unified process or independently developed and later merged. It is a matter of control. If the system is a set of independent systems, and you have no control over those decisions, then, maybe it' s a different kind of system. But again, we don' t see a clear-cut distinction between whether an enterprise system or a system of systems involves more or less of this independent decision making. Finally, complexity increases when the number of systems (developed as standalone entities or with interoperability in mind) and disparate stakeholders increase. The complex part is the interaction of people. Even though the concerns of IT governance may be more or less different, their interconnections and interactions can produce the desirable results, explaining why it is hardly a complex system. This section presents IT governance concerns using some complexity profiles, which are related to a fuzzy theory for characterizing the collective behavior of IT governance concerns.

### 2.1 Domain, Scope and DM Complexity

To understand the collective or cooperative behavior of IT governance system, it must be developed concepts that describe the collective behavior in a more general way. It is much easier to think about the problem of understanding collective behavior using the concept of a complexity profile. The complexity profile focuses attention on the scale at which a certain behavior of IT governance concerns is visible to an observer, or the extent of the impact it can have on its environment. The complexity profile counts the number of independent concerns that are visible at a particular scale and includes all of the concerns that have impact at larger scales. The central point is that when the independence of IT governance concerns is reduced, scale of behavior is increased. To make a large collective behavior, the individual concerns that make up this behavior must be correlated and not independent.
First, the domain complexity of IT governance concerns denotes a nonlinear function of what the decisions should consider. It comprises four complexity variables: Goals, processes, people and technology. Goals include strategy-related decisions, development and refinement of IT policies and guidelines, and control objectives used for performance assessments. Processes include the implementation and management of IT processes, e.g. acquisition, service level management, and incident management. People include the relational architecture within the organization, and the roles and responsibilities of different stakeholders. Finally, IT governance is of course about managing the technology itself. The complexity variable technology represents the physical assets that the decisions consider, such as the actual hardware, software and facilities. The practitioners prioritized the complexity variables as they are presented below.

- People variable: It denotes the relational structure within the organization, and the roles and responsibilities of different stakeholders.
- Goal variable: It denotes the development and refinement of an IT strategy, policies, guidelines, and control objectives to monitor whether the goals are achieved.
- Technology variable: It denotes the physical IT-related assets.
- Process variable: It denotes the implementation and management of IT processes and related activities and procedures.

Second, the scope complexity denotes a nonlinear function of different impacts implied by each decision. There is a long term aspect and a short time aspect of every decision that is made. Consequently, there is also a connection between the timeline of the decision and the level at which it is made. Top management make long time plans and set strategic goals, while lower management are authorized to make decisions affecting the near time. Further, strategically important decision requires more preparation than a tactic decision. The scope dimension is used to differentiate between different levels of decision-making. Firstly, there are detailed, rapidly carried out, IT-focused tactic decisions. Examples of tactic decisions include whether to upgrade a certain workstation today or tomorrow, how to configure a user interface that is only used internally, or the manning of a single IT project. There also exists top management, low detailed, business oriented strategic decisions with long timeline. A strategic decision might consider whether it is most appropriate to develop an application in-house or to purchase it off the shelf, or how the performance of IT processes should be reported to top management. The practitioners prioritized the dimensional units as they are presented below.

- Strategic variable: It is related to top-level management decisions, with few details and primarily a business impact. The decision features a business oriented focus with long timeline.
- Tactic variable: It is related to low-level management decisions, with many details and an impact primarily on IT. The decision has typically an operations focus and a short timeline.

Third, the decision making complexity denotes a nonlinear function of different steps required to make decisions within the different domains. This complexity deals with the relation between IT, and the models of the reality used for decision making. Before making any decision regarding e.g. the outsourcing of a helpdesk function, the organization must be clearly understood. Facts have to be thought over and investigated, and transformed into a model. The model might be a simple cognitive map, present nowhere else but in the head of the decision-maker, or a more formalized, abstract model put on print. This process of analysis and understanding is denoted the understanding phase. Once the model is created, the actual decision can be made according to corporate IT principles, in a timely manner, by the right individuals, etc. In the IT governance definition, this is represented by the decision phase, which also includes planning of how to make the decision. Finally, a decision is of little use unless its implementation is followed up and monitored. This can be accomplished by implementing control objects for each process in order to assess real-world performance. The decision-makers compare the state of the reality with the values obtained from the models. Note that these steps are not necessarily formal, but nevertheless exist in one way or another upon making decisions. The practitioners prioritized the complexity variables as they are presented below.

- Understand variable: It denotes the collection of information needed to make a correct decision.
- Decide variable: It is related to how and by whom the decision is made. Decisions are made according to corporate IT principles, at the correct level in an adequate forum, e.g. by a steering committee.
- Monitor variable: It denotes how the implications of a decision are monitored.

### 2.2 Formulation of type-2 fuzzy logic

A distinct advantage of type-2 fuzzy logic is that it is very powerful in handling uncertainties. IT Governance concerns model based on type-2 fuzzy logic can explicitly consider the domain, scope and decision-making complexity variables. By utilizing membership functions in type-2 fuzzy logic capable of handling uncertainty, the model can generate some collective behaviors of IT Governance concerns with reasonable accuracy. Compared with type-1 fuzzy logic, type-2 fuzzy logic has different definitions for membership functions. It also has its own set of operators. With these operators and the extension principle, the properties of type-2 fuzzy logic can be derived from type-1 fuzzy logic. The definition of type-2 fuzzy sets is given by

$$A = \{((x,u), \mu_A(x,u)) \mid \forall x \in X, \forall u \in J_x \subseteq [0,1]\}.$$

Here $0 \le \mu_A(x,u) \le 1$. A type-2 fuzzy set has additional dimension, $u$, associated with the membership value $\mu_A(x)$. That is, it has a membership function that would yield multi-valued $\mu_A(x)$ for $x=x'$. In particular, $u$ can be viewed as a type-1 fuzzy set, with the membership function $J_{x'}$ in three-dimensional space. $J_x$, a vertical slice of $\mu_A(x, u)$, is called the secondary membership function, denoted by

$$\mu_A(x = x', u) \equiv \mu_A(x') = \int_{u \in J_{x'}} f_{x'}(u)/u,$$

where $0 \le f_{x'}(u) \le 1$ and $f_{x'}(u)$ is the amplitude of a secondary membership function called a secondary grade. A integration symbol means that the type-2 fuzzy set has a membership $u$ associated with grade $f_{x'}(u)$ for $x=x'$. Note that, as is customary in the fuzzy logic notation, the integration symbol is not an integration operator but a symbol that represents the collection of all points of $u$ in $J_{x'}$.

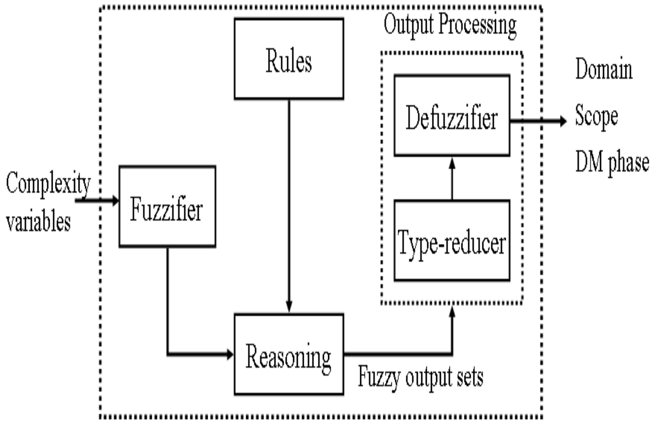



**Figure 1.** A type-2 FLS for IT Governance concerns

An interval type-2 fuzzy set is a special case of type-2 fuzzy sets in which the secondary membership functions are defined by $f_x(u)=1$, $\forall u \in J_x \subseteq [0,1]$. For $x=x'$, the primary membership value $u$ can be represented as an interval $[l, r]$. Since $X' \in X$, we can then drop the prime notation and refer to $\mu_A(x)$ as a secondary membership function. The type-2 fuzzy set can be defined as

$$A = \int_{x \in X} \mu_A(x)/x = \int_{x \in X} [\int_{u \in J_x} f_x(u)/u]/x, \ J_x \subseteq [0,1]$$

The domain of a secondary membership function is called the primary membership of $x$. $J_x$ is the primary membership of $x$, where $J_x \subseteq [0,1]$ for $\forall x \in X$. As in type-1 fuzzy logic, once the fuzzy set is defined, the fuzzy inference can be obtained based on the fuzzy set and the choice of operators for operations on the fuzzy set.

A type-2 fuzzy logic system is a rule-based system comprising five components: fuzzifier, fuzzy rules, inference, type-reducer and defuzzifier, as shown in Fig. 1. All the rules have antecedents and consequents. Based on the input and the antecedents of the rules, the fuzzy inference process will compute a 'firing level' for each rule, combine the consequents of the rules according to the firing level and then generate the resulting type-2 fuzzy set. The type-reducer and defuzzifier will perform the type-reduction and defuzzification to get a crisp value from the type-2 fuzzy set. This crisp value is the output of the type-2 fuzzy logic system.

# 3. Type-2 Fuzzy Logic for IT Governance Concerns

In this section, we discuss the type-2 fuzzy logic system in conjunction with our application. The type-2 fuzzy logic system developed for IT Governance concerns has the following five assumptions:

1. All the type-2 fuzzy sets are interval type-2 fuzzy sets.
2. Antecedent and consequent membership functions are Gaussian primary membership functions.
3. Input membership functions are Gaussian primary membership functions, with uncertain standard deviation.
4. The fuzzy operations use product implication and t-norm.
5. The type-reduction uses a centre-of-sets method and the defuzzification process uses a simple average method.

It is in general difficult to determine the exact probability density function for such a system. The interval type-2 fuzzy set and Gaussian primary membership functions are quite robust compared with other choices. These assumptions are made for simplifications in computation.

### 3.1 Membership functions

The interval type-2 fuzzy set has an upper membership function and a lower membership function. This property can be conveniently utilized to generate a prediction interval. In our formulation, Gaussian primary membership functions are used in two ways. We consider the use of a Gaussian primary membership function with a fixed standard deviation, $\sigma$, but uncertain mean in the following form:

$$\mu_A(x) = \exp\left[-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^2\right],\ m \in [m_1, m_2]$$

Denote exp(·) by N($m$, $\sigma$; $x$). For each value of m, there is a corresponding membership curve. The choice of $m_1$ and $m_2$ is based on the historical information. In the case of the interval type-2 fuzzy set, the upper membership function is defined by

$$\bar{\mu}_A(x) = \begin{cases} N(m_1,\sigma;x), & x \le m_1 \\ 1, & m_1 \le x \le m_2 \\ N(m_2,\sigma;x), & x > m_2 \end{cases}$$

whereas the lower membership function is defined by

$$\underline{\mu}_A(x) = \begin{cases} N(m_2,\sigma;x), & x \le (m_1+m_2)/2 \\ N(m_1,\sigma;x), & x \ge (m_1+m_2)/2 \end{cases}$$

Similarly, we can consider the use of a Gaussian primary membership function with fixed mean, $m$, but uncertain standard deviation:

$$\mu_A(x) = \exp\left[-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^2\right],\ \sigma \in [\sigma_1, \sigma_2]$$

For each value of $\sigma$, there is a corresponding membership curve. In the case of the interval type-2 fuzzy set, the upper membership function is

$$\bar{\mu}_A(x) \equiv N(m, \sigma_2; x)$$

The lower membership function is defined by

$$\underline{\mu}_A(x) \equiv N(m, \sigma_1; x)$$

### 3.2 Design of an IT Governance model based on type-2 fuzzy logic

There are five steps involved in the design of a type-2 fuzzy logic-based IT Governance concerns model:

#### 3.2.1 Design of the fuzzifier

The input data of a fuzzy logic system are a set of crisp values. The function of the fuzzifier is to transform the crisp values into a set of fuzzy values, that is, variables with a fuzzy membership function. In the IT Governance model, the fuzzifier will take the IT Governance concerns variable $x_k$ at the $k^{th}$ interval, $x'_k$, as an input to generate a type-2 fuzzy set. The membership functions used in our model are Gaussian primary membership functions with uncertain standard deviations given by

$$\mu_k(x_k) = \exp\left[-\frac{1}{2}\left(\frac{x_k - x'_k}{\sigma}\right)^2\right],\ \sigma \in [\sigma_1, \sigma_2]$$

It is reasonable to make the fuzzifier interval dependent since the mean concerns variables at different intervals are very different. The variance of the concerns variable, however, falls into a range with its boundary values determined from data across different data sets. The resulting membership function is shown in Fig. 2. For simplicity in notation, we omit the subscript to denote days here as well as in the following subsections.

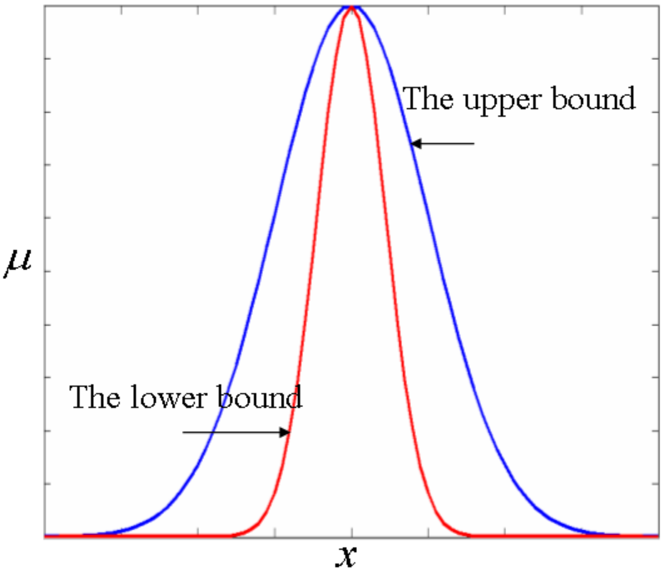



**Figure 2.** The type-2 fuzzy membership function with uncertain variance

### 3.2.2 The Construction of fuzzy rules

Once the set of type-2 fuzzy membership functions is defined, the next step is to construct the fuzzy rules for processing the fuzzy input. In our case, concerns data are used to build the fuzzy rules. It is similar to a training process in which data sets are utilized one by one to establish the centre of the fuzzy sets that appear in the antecedents and consequents of the rules. The $l^{th}$ fuzzy rule in the set with a total of $M$ rules has the format:

$R_l$ : IF $x_1$ is $F_1^{\,l}$ and . . . and $x_p$ is $F_p^{\,l}$

THEN $y$ is $G^l$, $l$=1, . . . , $M$

where $F_i^{\,l}$ is the antecedent, $G^l$ is the consequent of the $l^{th}$ fuzzy rule, $x_1, \ldots, x_p$ are the input of the fuzzy logic system and $y$ is the output for this rule, which will be utilized in fuzzy inference. In our model, rules are mostly developed based on historical information. Since the data available to us are quite limited, we use a single data set to construct a single fuzzy rule. This does not have to be the case. There are many alternative ways to construct fuzzy rules.

### 3.2.3 Design of the fuzzy inference engine

Fuzzy inference is the key component of the fuzzy logic system. Based on the input and the antecedents of the rules, it calculates a 'firing level' for each rule and then applies these firing levels to the consequent fuzzy sets. First, the union of two type-2 fuzzy sets $A$ and $B$ is expressed by

$$\mu_{A\cup B}(x) = \mu_A(x) \vee \mu_B(x), x \in X$$

The symbol $\vee$ denotes the join operator. Computationally, for any $x$, the join operator will enumerate all the possible combinations of u and w, take the maximum of $u$ and $w$ as the resulting primary membership value and take the minimum or product of the two secondary grades, $f_x(u)$ and $g_x(w)$, as the resulting secondary grade. In the interval type-2 fuzzy set, the join operator will be simplified as $\vee F_i$, $i$=1, …, $n$, representing the join of $n$ interval type-1 sets $F_1, \ldots, F_n$, having domains $[l_1, r_1], \ldots, [l_n, r_n]$, respectively, or $[(l_1 \vee l_2 \vee \ldots \vee l_n), (r_1 \vee r_2 \vee \ldots \vee r_n)]$.

The intersection of two type-2 fuzzy sets, $A$ and $B$, is expressed by

$$\mu_{A\cap B}(x) = \mu_A(x) \wedge \mu_B(x), x \in X$$

The symbol $\wedge$ here denotes the meet operator. Computationally, for any $x$, the meet operator will enumerate all the possible combinations of $u$ and $w$, take the minimum or product of $u$ and $w$ as the resulting primary membership value and take the minimum or product of the two secondary grades, $f_x(u)$ and $g_x(w)$, as the resulting secondary grade. This operation will give a new type-2 fuzzy set. For the interval type-2 fuzzy set, the meet operator will be simplified as $\wedge F_i$, $i$=1, …, $n$, representing the meet of n interval type-1 sets $F_1, \ldots, F_n$, having domains $[l_1, r_1], \ldots, [l_n, r_n]$, respectively, or $[(l_1 \wedge l_2 \wedge \ldots \wedge l_n), (r_1 \wedge r_2 \wedge \ldots \wedge r_n)]$.

In type-2 fuzzy logic systems, the output type-2 fuzzy set of the fuzzy inference of the $l^{th}$ fuzzy rule is:

$$\mu_{B^l}(y) = \mu_{G^l}(y) \wedge \{[\vee_{x_1} \mu_{X_1}(x_1) \wedge \mu_{F_1^l}(x_1)] \wedge \cdots \wedge [\vee_{x_p} \mu_{X_p}(x_p) \wedge \mu_{F_p^l}(x_p)]\},\ y \in Y$$

where $\mu_{X_i}(\cdot)$ is the type-2 membership function of the input, $\mu_{F_i^l}(\cdot)$ is the type-2 membership function of the antecedent $i$ of the $l^{th}$ rule, and $\mu_{G^l}(\cdot)$ is the type-2 membership function of the consequent of the $l^{th}$ rule. The above equation can be written as

$$\mu_{B^l}(y) = \mu_{G^l}(y) \wedge F^l(x')$$

where $F^l(x')$ is the firing level of the input data.

Since the interval type-2 fuzzy sets are used for IT Governance concerns, the firing level will also be an interval set:

$$F^l(x') = [\underline{f}^l(x'), \overline{f}^l(x')] \equiv [\underline{f}^l, \overline{f}^l]$$

Here

$$\underline{f}^l = \int_{\{x_1 \in X_1, \ldots, x_p \in X_p\}} [\underline{\mu}_{X_1}(x_1) \wedge \underline{\mu}_{F_1^l}(x_1)] \vee \cdots \vee [\underline{\mu}_{X_p}(x_p) \wedge \underline{\mu}_{F_p^l}(x_p)]/(x_1, \ldots, x_p)$$

$$\overline{f}^l = \int_{\{x_1 \in X_1, \ldots, x_p \in X_p\}} [\overline{\mu}_{X_1}(x_1) \wedge \overline{\mu}_{F_1^l}(x_1)] \vee \cdots \vee [\overline{\mu}_{X_p}(x_p) \wedge \overline{\mu}_{F_p^l}(x_p)]/(x_1, \ldots, x_p)$$

### 3.2.4 Type-reduction

For fuzzy reasoning of IT Governance concerns, the type-2 fuzzy set generated from the previous steps needs to be converted to a crisp value. This is realized through Steps 4) and 5), type-reduction and defuzzification. Type-reduction generates the centroid type-1 fuzzy set of a type-2 fuzzy set. There are several other methods for type-reduction, such as centre-of-sums type-reduction, height type-reduction, modified height type-reduction and centre-of-sets type-reduction. For the sake of computational efficiency, we employ the centre-of-sets type-reduction method. Instead of combining the type-2 sets from the fuzzy inference of all the rules before reduction, the centre-of-sets type reduction makes use of the centroid method to reduce the resulting type-2 sets from each rule and obtain a type-1 set $[L_i, R_i]$ for each rule $i$.

The weighted combination of these type-1 sets is then used to get the final type-1 set [$y_L$, $y_R$]:

$$y_L = \sum_{i=1}^{M} f_l^i L_i / \sum_{i=1}^{M} f_l^i$$

$$y_R = \sum_{i=1}^{M} f_r^i R_i / \sum_{i=1}^{M} f_r^i \cdot$$

Here $f_l$ and $f_r$ are the firing level corresponding to $y$ of rule $i$ that will maximize $y_L$ and minimize $y_R$. Each $f$ can be enumerated in the interval $[\underline{f}^i, \overline{f}^i]$.

#### 3.2.5 Defuzzification

Defuzzification is the last step to get the final forecast result. The defuzzification of a type-2 fuzzy logic system is identical to the defuzzication of a type-1 fuzzy logic system. There are also several methods for the defuzzification of a type-1 or a type-2 fuzzy logic system, such as the centroid defuzzifier, centre-of-sums defuzzifier, height defuzzifier, modified height defuzzifier and centre-of-sets defuzzifier. A commonly used defuzzification is the centroid method

$$y_c(x) = \sum_{i=1}^{M} y_i \mu_B(y_i) / \sum_{i=1}^{M} \mu_B(y_i),$$

in which the range of $y$ is discretized into $M$ points. The subscript 'c' denotes the centroid method. In the case of the interval set, we can defuzzify the interval [$y_L$, $y_R$] from type-reduction using the average of $y_L$ and $y_R$.

## 4. Application

The basis for IT governance application is the theoretical IT governance concerns. 100 sources of information on IT governance were identified when conducting an extensive literature search. The forums in which the articles have been published include the MIS Quarterly, Information Systems Control Journal, Information Systems Research, International Journal of Information Management, International Journal of Accounting Information Systems, and the Hawaii International Conference on System Sciences. 50 of the sources were selected randomly and analyzed in order to find common concerns. All statements used to create the IT governance complexity were again analyzed in order to extract the theoretical IT governance knowledge according to literature. The statements were classified and the number of times that each dimensional complexity was mentioned explicitly or implicitly was counted. figure 3 shows the results for these theoretical complexity variables, i.e. literature's concerns of IT governance. The total score for each dimension (e.g. Domain) is 100%.

The theoretical IT governance concerns show that the dimensional variables "People," "Strategic," and "Monitor" were most frequently used within the 50 articles and within their dimensions respectively. IT governance mainly comprises strategic concerns according to literature. The daily use of IT, all the operational concerns for bread-and-butter IT are surely important, but they are not in the scope of IT governance. Regarding the decision-making phases, monitoring of IT-related decisions is emphasized. In literature, IT control frameworks and legislations stipulating the need for internal control are often referred to, which is clearly reflected to in the figure. Technology issues are not the mayor concerns to decide upon, and literature rather stresses the importance of establishing roles and responsibilities, and an accountability framework that supports the business goals.

| | Complexity variables | Concerns according to Literature |
|---|---|---|
| Domain | People | 0.37 |
| | Goal | 0.26 |
| | Process | 0.2 |
| | Technology | 0.17 |
| Scope | Strategy | 0.7 |
| | Tactics | 0.3 |
| DM phase | Monitor | 0.42 |
| | Decide | 0.33 |
| | Understanding | 0.25 |

**Figure 3.** IT Governance concerns according to literature

Today, computing with words must still be done using numbers, and, therefore, numeric intervals must be associated with words. An earlier paper (Mendel, 1999) reported on an empirical study that was performed to determine how the scale 0–10 can be covered with words (or phrases). In typical engineering applications of fuzzy logic, we do not worry about this, because we choose the number of fuzzy sets that will cover an interval arbitrarily, and then choose the names for these sets just as arbitrarily. This works fine for many engineering applications when rules are extracted from data. One of the most striking conclusions drawn from the processed data is that linguistic uncertainty appears to be useful in that it lets us cover the 0~10 range with a much smaller number of terms than without it. Figure 4 depicts this for five terms (see Mendel, 2002). Solid lines are drawn between the sample means for the interval end-points and dashed lines are for the appropriate standard deviation about each mean end-point. Although five labels cover 0~10, there is not much overlap between some of them. It is when the standard deviation information is used that a sufficient overlap is achieved.

For simplicity, Figure 5 only illustrates fuzzy type-2 sets of the input variable "Process" and the output variable "Domain." They have each been divided into five overlapping sets labeled "none to very little," "some," "a moderate amount," "a large amount" and "a maximum amount." For the fuzzy sets of the input variable, we use the default ±0.1 standard deviation about each mean end-point. For the fuzzy sets of the output variable, we use the standard deviations corresponding to Fig.5. We can construct the fuzzy type-2 sets of Scope and DM complexity in a similar manner. Related to Domain complexity, twelve rules are defined in the rule base as shown below. We use the normalized rule weights for fuzzy pieces of IT governance concerns where twenty rules apply to the same conclusion.

If (Technology is none) then (Domain is none) (0.46)
If (Technology is some) then (Domain is none) (0.46)
If (Technology is moderate) then (Domain is some) (0.46)
If (Technology is large) then (Domain is some) (0.46)
If (Technology is maximum) then (Domain is moderate) (0.46)

If (Process is none) then (Domain is none) (0.54)
If (Process is some) then (Domain is none) (0.54)
If (Process is moderate) then (Domain is some) (0.54)
If (Process is large) then (Domain is moderate) (0.54)
If (Process is maximum) then (Domain is moderate) (0.54)
If (Goal is none) then (Domain is none) (0.7)
If (Goal is some) then (Domain is some) (0.7)
If (Goal is moderate) then (Domain is some) (0.7)
If (Goal is large) then (Domain is moderate) (0.7)
If (Goal is maximum) then (Domain is large) (0.7)
If (People is none) then (Domain is none) (1)
If (People is some) then (Domain is some) (1)
If (People is moderate) then (Domain is moderate) (1)
If (People is large) then (Domain is large) (1)
If (People is maximum) then (Domain is maximum) (1).

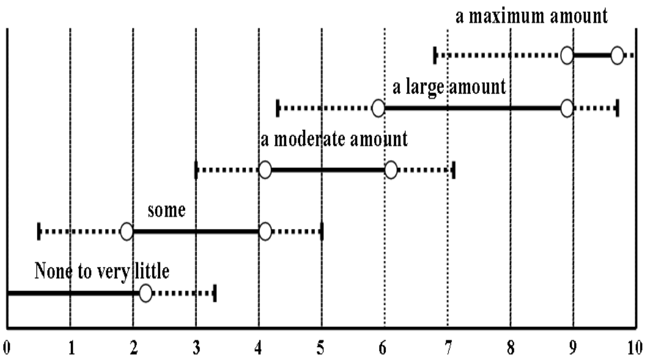



**Figure 4.** 5 labels and their intervals and uncertainty bands.

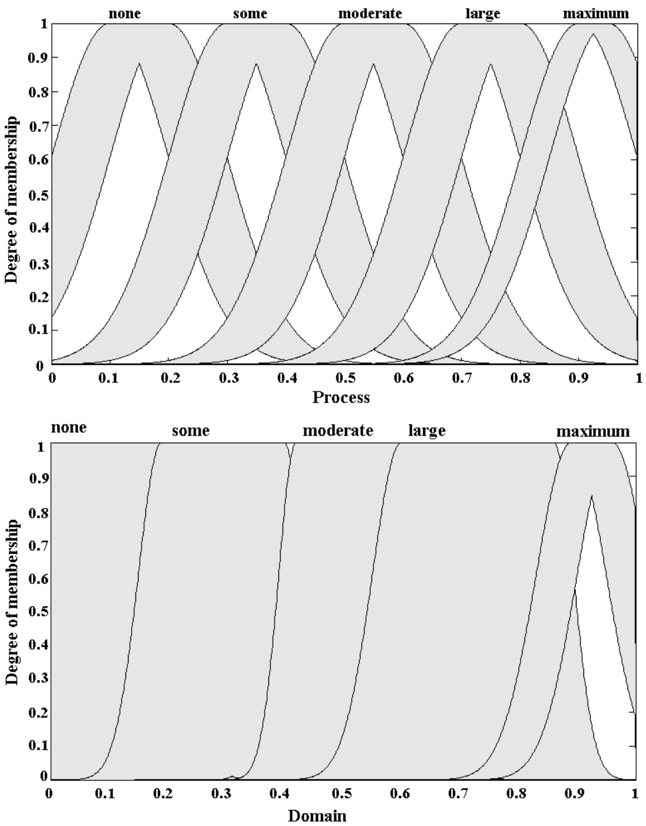
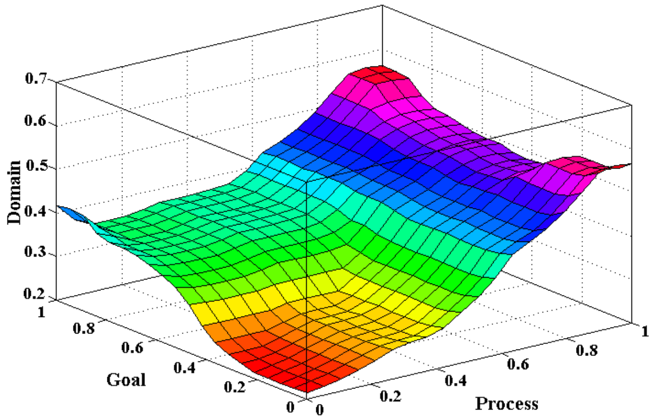
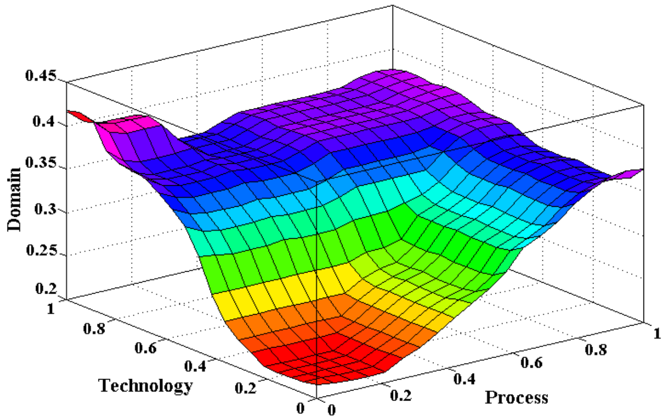
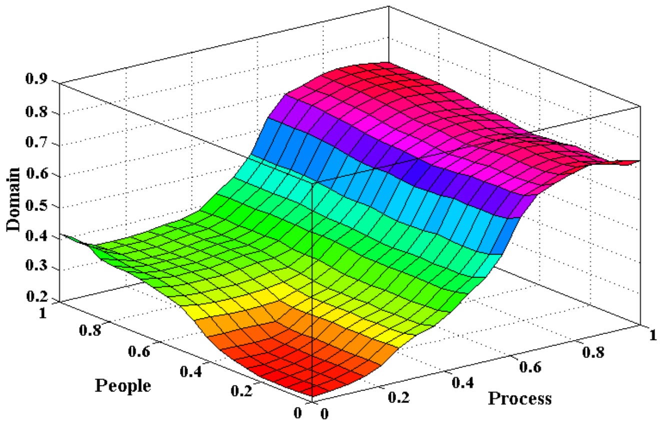
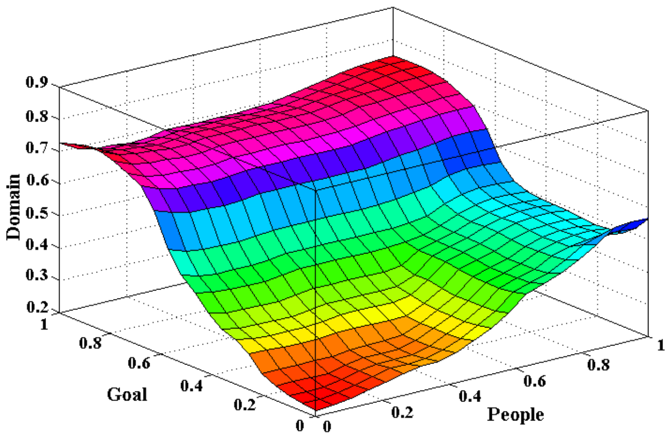



**Figure 5.** Fuzzy type-2 sets for "Process" and "Domain"



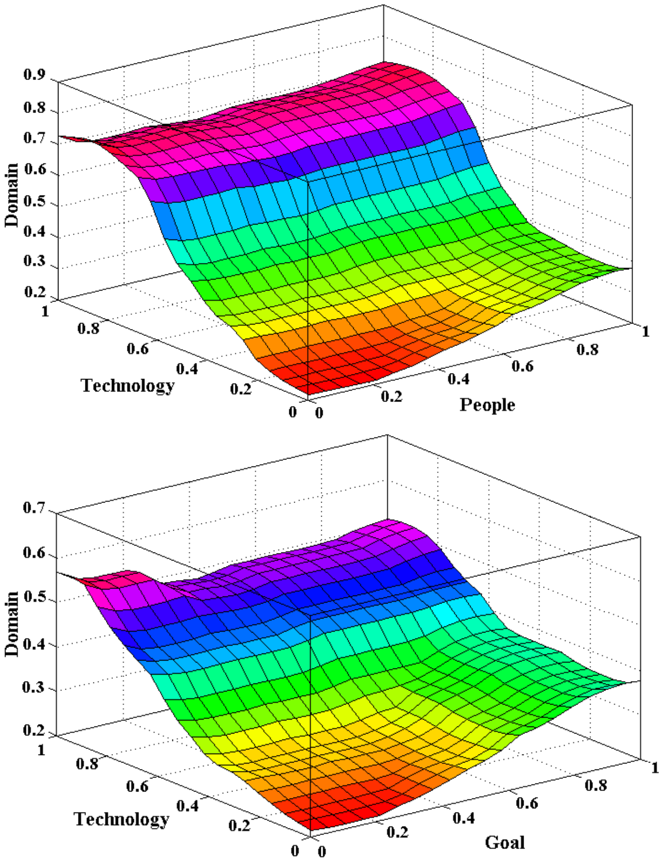



**Figure 6.** Mapping surface of Domain complexity.

Figure 6 shows the surface plots between the variables of Domain complexity. Clearly it is evident from the plot that "People" is more significant than other input variables. IT governance concerns in Literature denotes that "Technology" is less significant than other ones. But, considered as a whole, "Process" is less significant than other ones, c.f. (Fig 7). In particular, in proportion as "Goal" rises "Technology" concerns increase. Figure 7 illustrates the comparison of values estimated by using four input variables. According to the survey with practitioners, practitioner's concerns were mainly about IT goal setting, while IT processes and technology issues were less stressed. Figure 8 illustrates the comparison of values estimated by our fuzzy model. Here, "Goal" is more stressed. The result implies that the collective behaviors in which the concerns of practitioners affect other parts of the theoretical concerns must be no more complex. Generally speaking, it denotes that practitioners are faithful to the theoretical concerns. Compared to the concerns identified in literature, Cobit was focused on decisions regarding the processes while people receive less attention. Figure 9 illustrates the comparison of values estimated by our fuzzy type-2 model. The result denotes that there is discrepancy in the range of the concerns identified in literature.

| Process | Goal | Technology | People | Domain |
|---|---|---|---|---|
| 0.1 | 0.1 | 0.1 | 0.8 | 0.71 |
| 0.2 | 0.2 | 0.2 | 0.7 | 0.668 |
| 0.3 | 0.3 | 0.5 | 0.6 | 0.54 |
| 0.4 | 0.4 | 0.6 | 0.5 | 0.433 |
| 0.5 | 0.5 | 0.7 | 0.4 | 0.372 |
| 0.6 | 0.6 | 0.7 | 0.3 | 0.399 |

**Figure 7.** Comparison of values by fuzzy model.

| Process | Goal | Technology | People | Domain |
|---|---|---|---|---|
| 0.2 | 0.8 | 0.4 | 0.6 | 0.545 |
| 0.2 | 0.8 | 0.6 | 0.4 | 0.465 |
| 0.4 | 0.8 | 0.2 | 0.6 | 0.545 |
| 0.6 | 0.8 | 0.2 | 0.4 | 0.465 |

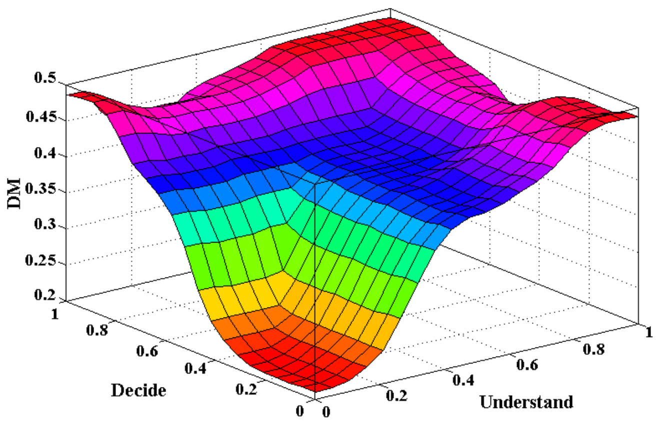
**Figure 8.** Comparison of values by practitioners' concerns.

| Process | Goal | Technology | People | Domain |
|---|---|---|---|---|
| 0.8 | 0.6 | 0.2 | 0.4 | 0.4 |
| 0.8 | 0.4 | 0.2 | 0.6 | 0.54 |
| 0.8 | 0.2 | 0.4 | 0.6 | 0.545 |
| 0.8 | 0.2 | 0.6 | 0.4 | 0.374 |

**Figure 9.** Comparison of values by Cobit.

Figure 10 shows the surface plots between input variables of DM and scope complexity, respectively. For DM complexity, the following fifteen rules and normalized weights are included in the fuzzy rule system.

If (Understand is none) then (Decision-making is none) (0.6)
If (Understand is some) then (Decision-making is none) (0.6)
If (Understand is moderate) then (Decision-making some) (0.6)
If (Understand is large) then (Decision-making is moderate) (0.6)
If (Understand is maximum) then (Decision-making is large) (0.6)
If (Decide is none) then (Decision-making is none) (0.79)
If (Decide is some) then (Decision-making is some) (0.79)
If (Decide is moderate) then (Decision-making is moderate) (0.79)
If (Decide is large) then (Decision-making is moderate) (0.79)
If (Decide is maximum) then (Decision-making is large) (0.79)
If (Monitor is none) then (Decision-making is none) (1)
If (Monitor is some) then (Decision-making is some) (1)
If (Monitor is moderate) then (Decision-making is moderate) (1)
If (Monitor is large) then (Decision-making is large) (1)
If (Monitor is maximum) then (Decision-making is maximum) (1)



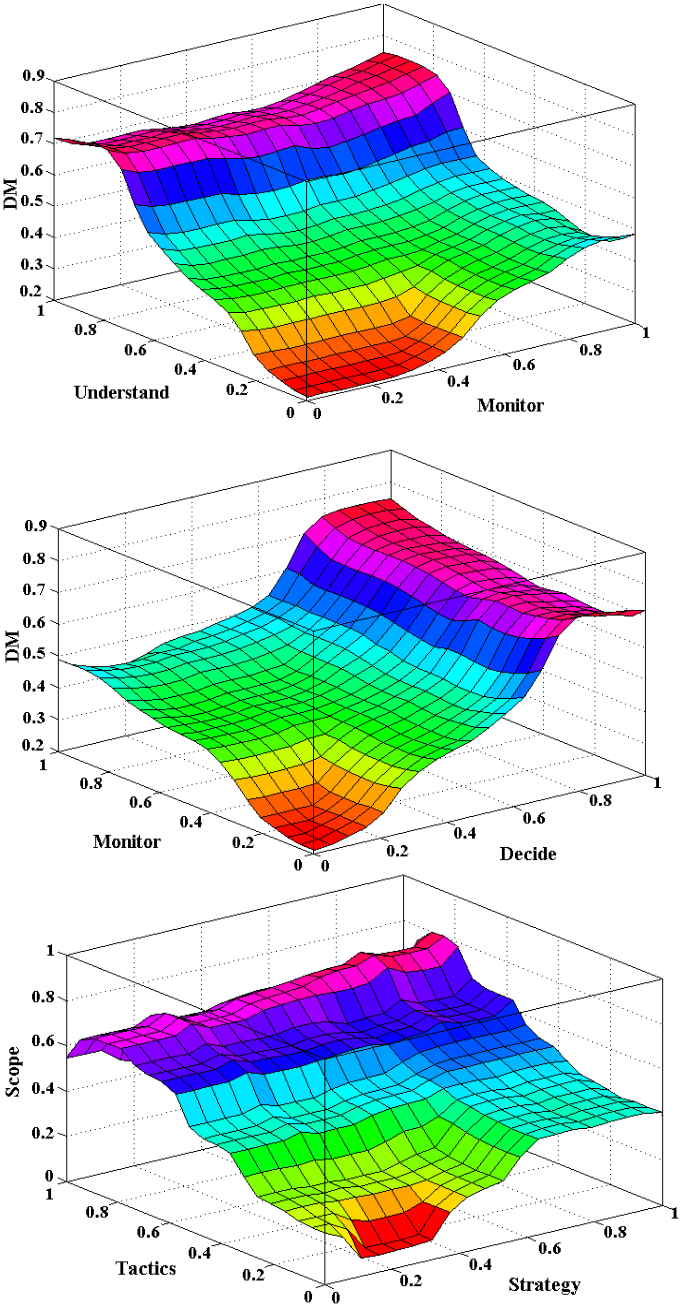



**Figure 10.** Mapping surface of DM and Scope complexity.

The theoretical concerns showed that the dimensional variable "Monitor" was more frequently used within the DM complexity. But, monitoring the implementation of decisions already made receives somewhat less attention from the practitioners, according to the survey. Also, comparing Cobit's concerns of IT governance to literature, it showed that Cobit does support most needs, but lacks in providing information on how decision-making structures should be implemented. Applied to our fuzzy type-2 model, the dimension variables of DM complexity are almost uniformly stressed. The relative concerns for the DM complexity remain a bit more uncertain. The difference seems to lie in their interconnection weights (and interactions) between the concerns of IT governance. For scope complexity, strategic concerns are most often dealt with, while tactical concerns are only briefly discussed. The following ten rules and normalized weights are included in the fuzzy rule system.

If (Strategy is none) then (Scope is none) (1)
If (Strategy is some) then (Scope is some) (1)
If (Strategy is moderate) then (Scope is moderate) (1)
If (Strategy is large) then (Scope is large) (1)
If (Strategy is maximum) then (Scope is maximum) (1)
If (Tactics is none) then (Scope is none) (0.43)
If (Tactics is some) then (Scope is none) (0.43)
If (Tactics is moderate) then (Scope is some) (0.43)
If (Tactics is large) then (Scope is some) (0.43)
If (Tactics is maximum) then (Scope is moderate) (0.43)

IT governance mainly comprises strategic concerns according to literature. According to the practitioners responding the survey, IT governance decision making is mainly a strategy issue while tactical decisions are less important. Similarly, Cobit spends more effort in discussing strategic concerns and less on tactical concerns. But, according to the mapping surface of Figure 6, strategic and tactical concerns that make up a large collective behavior must be correlated and not independent.

## 5. Summary

This paper presented a fuzzy type-2 model to understand the relationship among IT governance concerns. The fuzzy type-2 logic presents a specific architecture for making judgments by computing with words. To assess the IT governance concerns is equal to make the judgments through computing with words. Compared with our previous work, results showed the more exact relations of the IT governance concerns than using fuzzy type-1 model. Similarly, the application results showed that the major differences exist within the concerns of the domain complexity in the case of Cobit. Really, Cobit was focused on decisions regarding the processes while people receive less attention. In conclusion, an analysis based upon these mathematical models suggested that IT governance itself is an organism capable of behaviors that are of greater complexity than those of an individual IT governance concerns. What makes something complex is that the concerns of IT governance is evolving. There is still room to further improve the performance of the proposed model. For example, currently in the model-building process we have made no attempt to tune the parameters to optimize the performance of the model. This is in part because there are only limited data sets available to us. In future studies, we should obtain data from other sites and automate the model calibration process. Research is ongoing to test other methods for constructing fuzzy rules and tie the use of a specific method with the characteristics of the IT governance concerns.

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