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A Fuzzy Model of Scenario Planning Based on the Credibility Theory And Fuzzy Programming

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Abstract Uncertainty, complexity and paradigm shift are three challenges that are inherent in emerging technologies. Based on the scenario construction and empirical four foresight stages, Credibility theory and fuzzy programming are introduced to dissolve scenario planning problems. And then, a fuzzy model for scenario planning is proposed.

Keywords Scenario planning; Credibility theory; Fuzzy programming

1 Introduction

Scenario planning is an important method of futures research and forecasting. Scenarios provide a background for decision-making by clarifying possible paths of development and environmental conditions of the forthcoming times.

In the case of emerging technologies, there are three particular challenges that seldom can be answered by other forecasting techniques than scenarios: uncertainty, complexity and paradigm shift (Schoemaker 2000). Unlike risk, uncertainty cannot be expressed with precise figures and therefore it is difficult to include this factor in any traditional planning model. However, in scenario planning uncertainty is a necessity as there is no point in creating alternative visions if one of them is already known to come true. Complexity is a result of different forces such as social, technological and economic interacting with each other. Properly extensive scenarios should perceive this interaction, as it is important that a scenario is a consistent entity. Scenarios, along with the weak signals or emerging phenomena, also alleviate change in the prevailing state as they challenge the current assumptions questioning “what if”.

Traditional forecasting methodologies either are based on collected data of the past, or are based on the qualitative and subjective estimation. The former, such as time-series analysis, try to extrapolate new ideas about future developments based on knowledge of and experience with the past and present (Makridakis and Wheelwright, 1978, Opitz, 1985). In fact, these methods imply that the past environments are also suitable to the future. The later, such as Delphi method, brainstorming, brainwriting, etc. are mainly based on the interview or questionnaire to the experts. Though the knowledge and the experience of experts is often the data sources in a strategic planning (Sarin, 1979), how to evaluate the factors and the relationship between them is difficult for many experts. Therefore, it is necessary to supplement the traditional methods so that the forecasting methods can cope with the requirements of the uncertainty, complexity and the dynamic environments.

Contrasting to the traditional forecasting methodologies, scenario planning is not based on the past data but considers qualitative and subjective information of experts to conduct scenario and conduct analysis. Based on the scenario construction and the empirical four foresight problems, this study introduces credibility theory and fuzzy programming into scenario construction and analysis.

2 Literature Review

Since the 1970s, both academics and practitioners have propagated multiple–scenario planning to deal effectively with the many uncertainties that surround the future of business organizations. Based on the difference of the world view and research methodology, we can divide the kingdom of scenario planning into two genres.

One genre attempt to evaluate the probabilities of the series of scenarios, using probability theory, cross-impact analysis and Monte Carlo simulations, they believe that they can get the solution of the optimization problem (Gordon and Hayward, 1968; Sarin, 1978, 1979; Jutta Brauers and Martin Weber, 1988). To them, the uses of scenarios and scenario development are evaluation and selection of strategies, integration of various kinds of future-oriented data, exploration of the future and identification of future possibilities.

Another genre think that scenario planning is not aimed at obtaining forecasts but advocates the creation of alternative images of the future development of the external environment (Theo J.B.M. Postma, Franz Liebl, 2005). Scenario planning differs from many other planning techniques in its goal of a paradigm shift by painting concrete and vivid narratives of the future that hinge on key uncertainties whose outcomes will shape the future environment (Paul J.H. Schoemaker and V. Michael Mavaddat, 2000). And, scenario planning can reveal the meaning of the development, inspire the out-of-box and make our feeling more acuity (Kees van der Heijden et al., 2002). To them, scenarios aim at making managers aware of environmental uncertainties, stretching managers' mental models, and triggering and accelerating processes of organizational learning.

In fact, these two genres are not incompatible, as P. Wack puts it: "scenarios deal with two worlds: the world of facts and the world of perception" (P. Wack, 1985).

3 Empirical Scenario Construction for Foresight Problems

At present, there are no universal and comprehensive approaches to and methods for foresight of future events and phenomena. There are only attempts to construct possible scenario, realization of definite sequence of events under anticipated conditions (M. Z. Zgurocskii and N. D. Pankratova, 2003). Several methods are used at four foresight stages during this process. See Table 1.

Table 1. Four Stages of Technology Foresight

Stage	Methods	Features of Each Method	Purpose
First stage	Scanning method	Formulate and clusterize all constructive ideas and approaches.	Preliminary study
	Brainstorm method	Analyze the predefined direction of the upper study	
Second stage	The Delphi method	A group of experts in a definite knowledge domain, give the evaluation for each factor	Comprehensive study
	Cross-impact analysis	Search for values of calculated events and scenario probabilities using mathematical programming	
	The Saati method	Search for values of calculated events and scenario probabilities using mathematical programming, especially when possible scenarios cannot be described verbally.	
	Morphological analysis	Possible scenarios are calculated, intersections of morphological space of characteristic parameters for the systems under study are looked for.	
Third stage	Scenario construction	Systems construction of integral scenarios	Rehearse future
Fourth stage	Bayesian models	Analyze and chose the main scenarios	Make decisions

Empirical scenario construction consists of three basic stages (Gomez and Escher, 1980), viz. analysis phase; description of future states of environment subsystems; and syntheses phase.

In the first stage, it is necessary to define the entity of the question to be solved. Afterwards, subsystem analysis is conducted, which consists of the identification of relevant external influences on the entity of the question to be solved. In the third stage, it is considered that existing interdependencies between the factors and establishing alternative scenarios through the synthesis of these future states.

4 Credibility Theory And Fuzzy Programming for Scenario planning

Credibility theory is a branch of mathematics that studies the behavior of fuzzy phenomena. The concept of fuzzy set was initiated by Zadeh via membership function in 1965. Zadeh proposed the concept of possibility measure in 1978. From then on, possibility measure was widely used in solving fuzzy problems. According to Prof. Liu B (2002), possibility measure has no self-dual measure, and a self-dual measure is absolutely needed in both theory and practice. In order to define a self-dual measure, Liu B and Liu YK present the concept of credibility measure in 2002. An axiomatic foundation of credibility theory was given by Liu B in 2004.

Definition 1: Credibility Measure

Let Θ be a nonempty set, and $\mathrm{P}(\Theta)$ the power set of Θ. Each element in

$\mathrm{P}(\Theta)$ is called an event. In order to present an axiomatic definition of credibility, it is necessary to assign to each event A a number $Cr\{A\}$ which indicates the credibility that A will occur. In order to ensure that the number $Cr\{A\}$ has certain mathematical properties that we intuitively expect a credibility to have, Liu and Liu presented the following five axioms:

Axiom 1. $Cr\{\Theta\}=1$.

Axiom 2. Cr is increasing, i.e., $Cr\{A\} \le Cr\{B\}$ whenever $A \subset B$.

Axiom 3. Cr is self-dual, i.e., $Cr\{A\} + Cr\{A^c\} = 1$ for any $A \in \mathrm{P}(\Theta)$.

Axiom 4. $Cr\{\bigcup_i A_i\} \wedge 0.5 = \sup_i Cr\{A_i\}$ for any $\{A_i\}$ with $Cr\{A_i\} \le 0.5$.

Axiom 5. Let Θ_k be nonempty sets on which Cr_k satisfy the first four axioms, $k = 1, 2, \cdots, n,$ respectively, and $\Theta = \Theta_1 \times \Theta_2 \times \cdots \times \Theta_n$.

Then $Cr\{(\theta_1, \theta_2, \cdots \theta_n)\} = Cr_1\{\theta_1\} \wedge Cr_2\{\theta_2\} \wedge \cdots \wedge Cr_n\{\theta_n\}$,for each $(\theta_1, \theta_2, \cdots \theta_n) \in \Theta$ .In that case we write $Cr = Cr_1 \wedge Cr_2 \wedge \cdots \wedge Cr_n$. The set function Cr is called a credibility measure if it satisfies the first four axioms.

Definition 2: Fuzzy Variable

A fuzzy variable is defined as a function from a credibility space $(\Theta, \mathrm{P}(\Theta), Cr)$ to the set of real numbers.

Definition 3: Membership Function

Let ξ be a fuzzy variable defined on the credibility space $(\Theta, \mathrm{P}(\Theta), Cr)$. Then its membership function is derived from the credibility measure by

$$\mu(x) = (2Cr\{\xi = x\}) \wedge 1, \quad x \in \Re \tag{1}$$

Definition 4: Triangular Fuzzy Variable And It's Membership Function

A triangular fuzzy variable is that the fuzzy variable fully determined by the triplet (a, b, c) of crisp numbers with $a < b < c$, whose membership function is given by

$$\mu(x)=\begin{cases}\dfrac{x-a}{b-a}, & if \quad a\le x\le b\\ \dfrac{x-c}{b-c}, & if \quad b\le x\le c\\ 0, & otherwise\end{cases} \tag{2}$$

Definition 5: Credibility Distribution (Liu B, 2002)

The Credibility distribution $\Phi:\Re\to[0,1]$ of a fuzzy variable ξ is defined by

$$\Phi(x)=Cr\{\theta\in\Theta \mid \xi(\theta)\le x\} \tag{3}$$

That is, $\Phi(x)$ is the credibility that the fuzzy variable ξ takes a value less than or equal to x.

Definition 6: Credibility Distribution of a Triangular fuzzy variable (a,b,c) is

$$\Phi(x)=\begin{cases}0, & if \quad x\le a\\ (x-a)/2(b-a), & if\ a\le x\le b\\ (x+c-2b)/2(c-b), & if\ b\le x\le c\\ 1, & if \quad x\ge c\end{cases} \tag{4}$$

Based on Brauers and Weber's method and Hsiao-Fan Wang's fuzzy approach in scenario planning, this paper adopt such research path as (1) analysis of factors' credibility through credibility measure, (2) analysis of pairwise factors' compatibility, (3) eliminate incompatible scenarios through pruning rules, and (4) choice of scenarios through fuzzy programming

4.1 Analysis of Factors' Credibility

Based on the probability measure, event A's credibility measure is given as follows. Assume that $(\Theta, \mathrm{P}(\Theta), \mathrm{P}_r)$ is probability space, A is one element of power set $\mathrm{P}(\Theta)$, then

$$Cr\{A\}=\frac{1}{2}(1+Pr\{A\}-Pr\{A^c\}) \quad \text{for each} \quad A\in \mathrm{P}(\Theta) \tag{5}$$

We call $Cr\{A\}$ the credibility measure of event A.

4.2 Analysis of Pairwise Factors' Compatibility

Based on the Battelle method (Geschka and Reibniz, 1979; Oberkampf, 1976; von Reibnitz, 1981, 1983), in order to determine the interdependence between the individual outcomes, the compatibility of the pairwise outcomes e_i and e_j $\left(i, j = 1, 2, \cdots, n\right)$ is determined at this stage, which is marked $\tilde{k}_{ij}$. And in order to fully express the expertise, the degrees of compatibility between the pairwise outcomes are expressed by a fuzzy number set in the form of a triangular fuzzy variable:

$$\tilde{k}_{ij} = (l(\tilde{k}_{ij}), m(\tilde{k}_{ij}), u(\tilde{k}_{ij})) = (\tilde{k}_{ij}, \mu(\tilde{k}_{ij})) l(\tilde{k}_{ij}) \le \tilde{k}_{ij} \le u(\tilde{k}_{ij}) and\, \mu(m(u(\tilde{k}_{ij})) = 1 \forall i, j \tag{6}$$

$\tilde{k}_{ij}$ are integers ranged from $\tilde{1}$ to $\tilde{5}$, if two outcomes are incompatible they are assigned the value $\tilde{1}$. A compatibility rating of $\tilde{5}$ indicates that they are very compatible. The in-between values $\tilde{2}, \tilde{3}\, and\, \tilde{4}$ represent increasing compatibility. $l(\tilde{k}_{ij}), m(\tilde{k}_{ij}), u(\tilde{k}_{ij})$ are lower, middle and upper points of triangular $\tilde{k}_{ij}$.

The triangular fuzzy variable $\xi = (a, b, c)$ has an expected value $E\left[\xi\right] = \frac{1}{4}(a + 2b + c)$, and then the expected value of the compatibility of pairwise outcomes can be expressed by

$$E\left[\tilde{k}_{ij}\right] = \frac{1}{4}(l(\tilde{k}_{ij}) + 2m(\tilde{k}_{ij}) + u(\tilde{k}_{ij})) \tag{7}$$

The triangular fuzzy variable $\xi = (a, b, c)$ has a variance value $V\left[\xi\right] = (c - a)^2 / 24$, and then the variance value of the compatibility of pairwise outcomes can be expressed by

$$V\left[\xi\right] = (u(\tilde{k}_{ij}) - l(\tilde{k}_{ij}))^2 / 24 \tag{8}$$

4.3 Compatible Analysis of Scenarios

For large problems, there will be large number of outcomes, and then will produce a large number of scenarios, because the number of scenarios are exponentially growing with the number of outcomes. In this case, we should prune some scenarios which are incompatible and choose the scenarios with the fewest number of compatibility ratings of $\tilde{2}$ and/or which have the highest average compatibility values. We can do this following such rules:

(1) Eliminate the scenarios whose rating of compatibility has a value of $\tilde{1}$ ($m(\tilde{k}_{ij})$ =1).

(2) Eliminate the scenarios that have the lowest average degrees of compatibilities defined by $\sum_{\substack{a_{ki}=1\\a_{kj}=1}}\sum_{i<j}\sum_{x\in\tilde{k}_{ij}} x\cdot\mu(x)\Big/\left|\tilde{k}_{ij}\right|$, $\forall k$, or the great total sum of the membership of the compatibility $\tilde{2}$ defined by $\sum_{\substack{a_{ki}=1\\a_{kj}=1}}\sum_{i<j}\sum_{x\in\tilde{k}_{ij}}\sum_{x=2}\mu(x)$, $\forall k$, where if the k-th scenario contains the i-th outcome, then $a_{ki}=1$, otherwise $a_{ki}=0$.

4.4 Choice of Scenarios and Fuzzy Programming Model

The choice of scenarios can be conducted by expected value model, as follows.

$$\begin{aligned}&\max \quad \omega E\left[\sum_{i=1}^{n}\xi_i x_i\right]-(1-\omega)V\left[\sum_{i=1}^{n}\xi_i x_i\right]\\&s.t. \quad \sum_{i=1}^{n}x_i=1\\&x_i\ge 0, i=1,2,\cdots n.\end{aligned}\tag{9}$$

Where ξ_i is the fuzzy variable, represents the compatibility of scenarios; x_i is the decision variable, represents the degree which the decision maker should take into account. $\omega\in[0,1]$ represents the risk degree which the decision maker can bear. $\omega=0$ represents that the decision maker extremely risk detested, and $\omega=1$ represents that the decision maker extremely risk favored. $\sum_{i=1}^{k}x_i=1$ represents that the decision maker has k scenarios which can be considered.

5 Conclusion

In this paper, based on the scenario construction and empirical four stages of technology foresight problems, we introduced credibility theory into scenario planning and proposed a fuzzy model for scenario choice.

The imperfection for this paper consists in having not verified the model through conducting experiment or simulation. Farther research should include such fields as (1) how to solve the fuzzy model; (2) how to manifest the validity of the model; and (3) how to apply scenario planning to concrete foresight problems.

References

[1] Hsiao-Fan Wang. A Fuzzy Approach Scenario planning in Strategic Planning, *IEEE International Systems Conference Proceedings*, 1999, 22-25, Seoul, Korea.

[2] M. Z. Zgurocskii, N. D. Pankratova. An Information Platform for Scenario planning in Technology Foresight Problems, *Cybernetics and Systems Analysis*, 2003, 39, 564-574.

[3] Theo J.B.M. Postma, Franz Liebl. How to Improve Scenario planning as a Strategic Management tool?, *Technological Forecasting & Social Change*, 2005, 72, 161-173.

[4] Cornelis A. DE Kluyver, Herbert Moskowitz. Assessing Scenario Probabilities via Interactive Goal Programming, *Management Science*, 1984, 30, 273-278.

[5] Paul J.H. Schoemaker, Cornelius A.J.M, van der Heijden. Integrating Scenarios into Strategic at Royal Dutch/Shell, *Planning Review*, 1992, 20, 41-46.

[6] Harold S. Becker. Developing and Using Scenarios – Assisting Business Decisions, *The Journal of Business & Industrial Marketing*, 1989, 4, 61-70.

[7] Jutta Brauers, Martin Weber. A New Method of Scenario planning for Strategic Planning, *Journal of Forecasting (1986-1988)*, 7, 31-47.

[8] Kees van der Heijden. 2005. *Scenarios: The Art of Strategic Conversation*. Chichester & New York: John Wiley & Sons.

[9] Kees van der Heijden, Bradfield R, et al. 2002. *The Sixth Sense, Accelerating Organizational Learning with Scenarios*, Chichester & New York: John Wiley & Sons.

[10] George S. Day, Paul J.H. Schoemaker, Robert E. Gunther. 2000. *Wharton on Management Emerging Technologies*, Chichester & New York: John Wiley & Sons.

[11] B Liu. 2005. Foundation of Uncertainty Theory, *A Rough manuscript for Distribution in Uncertainty Theory Laboratory Only*.

[12] B.Liu, Y.K.Liu. Expected value of fuzzy variable and fuzzy expected value models. *IEEE Transactions on Fuzzy Systems*, 2002, 10(4):44 5-450.