INCORPORATING FUZZY COGNITIVE MAP (FCM) INTO TECHNOLOGY ROADMAPPING (TRM) FOR SCENARIO PLANNING

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Abstract—This paper proposes anintegrated approach of fuzzy cognitive map and technology roadmap for scenario planning. Previous attempts to scenario-based technology roadmapsfor responding to the uncertainties, however, are limited toonly external uncertainty and given scenarios. As a remedy, fuzzy cognitive map is integrated to analyze the scenarios under internal and external uncertaintiesand to make decision on roadmapping elementsaccording to dynamic scenarios.

Index Terms—Fuzzy Cognitive Map, Technology Roadmap, Scenario Planning, Uncertainty

I. INTRODUCTION

Today, as the uncertainty and risk around technology innovation has been significantly increased; technology planners are required to consider not only external uncertainties but uncertainties in internal environment and decision making process[1]. In response, Technology RoadMap (TRM), a representative planning tool consisting of multi-layers of business/market, products/services, and technologies/capabilities and resources[2], has been elaborated into a scenario-based TRM to explore alternative trajectories of the future[3].

One stream of existing studies on scenario-based TRMsuggested conceptual frameworks revising the structure of the map and roadmapping processes [3]-[5]. Other research stream attempted to integrate quantitative methods for scenario-based TRM using such methods as Bayesian network[6], system dynamics[7], and cross-impact analysis[8].

However, previous research has critical limitations in two aspects. First, most of them involve only external business/market uncertainties, and are lack of considering the uncertainties in internal technologies/capabilities developments and decision making of products/services. Second, they usually assume scenarios are given typically as neutral, positive and negative rather than establish scenarios flexible manner. Under various types of uncertainties, it is hard to simply presetting scenarios.

As a remedy, this study proposes an integrated approach of Fuzzy Cognitive Map (FCM) and Technology Roadmap (TRM) forscenario planning. FCM is an extended cognitive map within which the relations between the concepts of a mental landscape can be used to compute the 'strength of impact' of these concepts[9]. FCM has several advantages in scenario planning[10]. First, as a modeling tool, itcan extract cognitive models of scenarios from experts[9]. Second, it can engage the probability of concepts and the positive or negative impacts of causal relationships [11]. If the concepts are modeled as internal and external factors, their probabilities can represent both internal and external uncertainties. Third, as a simulation tool, it can support what-if experiments [10], [12], by setting input conditions of scenario, simulating model, and analyzing outputs.

In the remaining parts, this paper reviews FCM-based scenario analysis, suggests the integrated FCM-TRM approach in detail, and ends up with conclusions.

I. FCM-BASED SCENARIO ANALYSIS

A. FCM

FCM (Fuzzy Cognitive Map), firstly suggested by Kosko[9], is anextension and enhancement of cognitive map to represent a belief system in agiven domain.The elements of a FCM are as follows [11]:

- Concepts: C_1, C_2, … , C_n. These represent the drivers and constraints that are considered of importance to the issue under consideration.
- State vector: $A = (a_1, a_2, \dots, a_n)$, where a_i denotes the state of the node C_i. The state vector represents the value of the concepts, usually between 0 and 1. The dynamics of the state vector is the principal output of applying a FCM.
- Directed edges: $C_1 \rightarrow C_2$, etc. These represent the relationships between concepts, visualized as arrows in the directed graph.
- Adjacency matrix: $E = (e_{ij})$, where e_{ij} is the weight of the directed edge C_i to C_j. The matrix contains the values of all relationships between concepts, usually between -1 and +1. Note that contrary to most applications, non-zero values on the diagonal are considered here.

B. Scenario Analysis Using FCM

Scenarios are defined as a set of hypothetical events in the future constructed to clarify a possible chain of causal events as well as their decision points [13]. As the consideration of scenarios can significantly enhance the ability to deal withuncertainty and the usefulness of overall decision making process, scenario planning has been adopted technology planning or strategic analysis.

The following framework has been proposed for development of FCM-basedscenarios by integrating scenario planning and FCM modeling processes [10], [12]:

- Step 1 Scenario preparation: Clarification of the objective, time frame andboundaries of the scenario project.
- Step 2 Knowledge capture: Identify relevant concepts/potential scenario driversthrough experts and literature review, merge mental models of variousexperts and subsequently translate these into conceptual FCM scenariomodel.
- Step 3 Scenario modeling: Streamline the causal links and assign weights andsigns to all links, choose squashing functions for all concepts.
- Step 4 Scenario development: Calculate the FCM model for different inputvectors that represent plausible combinations of concept states.
- Step 5 Scenario selection and refinement: These raw scenarios developed afterstep 4 are further assessed and refined by scenario simulation.
- Step 6 Strategic decisions: The developed scenarios are used for making longterm strategic decisions.

II. INTEGRATED FCM-TRM APPROACH

C. Overview

Overall process of integrated FCM-TRM approach is described in Fig. 1.

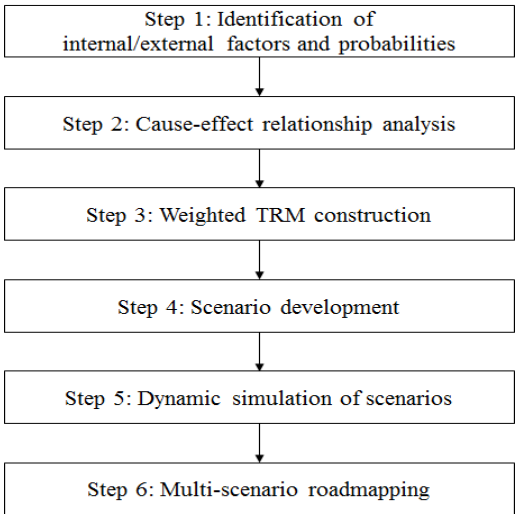


Fig. 1.Research process

The process comprises sixsteps: after modeling the planning factors in step 1 to 3 (identification of internal/external factors and probabilities, cause-effect relationship analysis, and weighted TRM construction); scenarios are analyzed in step 4 and 5 (scenario development and dynamic simulation of scenarios); and finally scenario planning is completed in step 6 (multi-scenario roadmapping).

D. Detailed Process

1) Identification of factors and probabilities

The 'external factors'includingbusiness/market drivers (M_1, M_2, … ,M_n), and 'internal factors' including products/services (P_1, P_2, … , P_n), and technologies/capabilities and resources (T_1, T_2, … , T_n) are identified. In addition, the third type, 'outcome factors'(O_1, O_2, … , O_n) that represents the performance of planning and innovation are defined. Also, the uncertainty of each factors are evaluated as 'probabilities of occurrence or success', between 0 and 1. This configures the state vector of FCM.

2) Cause-effect relationship analysis

In order to assign the causal weights, case-effect relationship matrix is constructed.As shown in Fig. 2, all factors are placed in the raw and column of the matrix and their relationships are measured as the 'value of causal weight', between -1 and +1. The blue-colored sections of matrix mean the intra-layer relationships and other sections correspond to the inter-layer relationships in TRM.

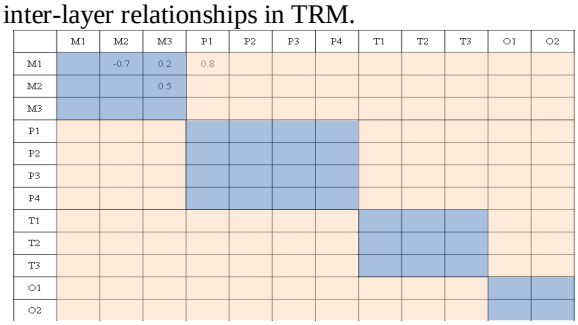


Fig. 2. Example of cause-effect relationship matrix

3) Weighted TRM construction

The factors and values identified in previous stages are visualized as 'weighted TRM' structure, an integrated model of TRM and FCM. In weighted TRM,the weights follows FCM notation:the probabilities of factors in the nodes and the causal weights in the edges, but the factors are divided into TRM layers. Weighted TRM is a pre-form of TRM that does not consider the strategic decision, which are subsequently determined according to the scenarios.

4) Scenario development

In this study, any combination of the binary state of factors in weighted TRM can be an 'input vector', starting condition or background of one scenario. In developing FCM-basedscenarios, morphological analysis[14] has been usually appliedin this stage [10]. As shown in the example of Table 1, the variations for each factor in weighted TRM are identified.

Table 1. Example of morphological analysis matrix

	Scenario projection			Strategic options			
	M_1	M_2	M_3	P_1	P_2	T_1	T_2
Variation A	…	…	…	…	…	…	…
Variation B	…	…	…	…	…	…	…

Based on the morphological analysis matrix, consistency analysis is conducted to remove inconsistent combinations and input vectors are finalized as the consistent set of variations.

5) Dynamic simulation of scenarios

FCM can incorporate the dynamic simulation to identify an 'output vector' for given input vector. Since an input vector is the plausible conditions of a scenario and output vector is its expected results based on causal relationships in the future, the set of input and output vectors configures one scenario. This can lead to what-if experiments because different input vector can generate different output vector.

The dynamic simulation references existing approach of FCM-based scenarios [10]. FCM simulation isperformed by multiplying the input vector with the FCM adjacency matrixuntil the output vector is stabilized. As the results of the step 5, the outcome factors from output vectors of scenarios can be investigated. Since we involved strategic options in the input vector, the outcome factors of output vector stands for the performance outcome of strategic options in the future.

6) Multi-scenario roadmapping

Finally, multi-scenario TRMs are developed by representing the strategic decisions for the scenarios as shown in Fig. 3.

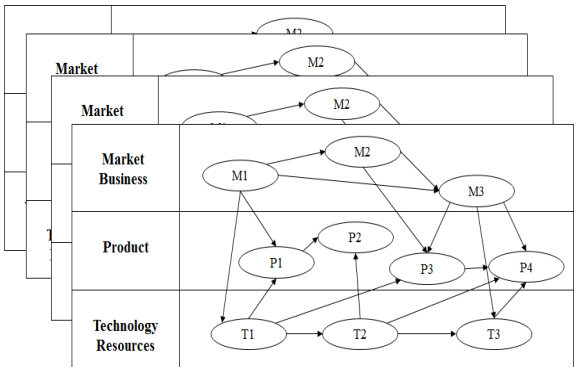


Fig.3.Concept of multi-scenario roadmapping

CONCLUSION

This paper proposed the integrated FCM-TRM approach to scenario planning. The approach can provide remedial attempt responding to the limitations of scenario-based TRM. First, in terms of the balanced consideration of internal and external uncertainty, the framework assigned the probabilities of occurrence or success to both internal and external factors.Second, in the viewpoint of flexible scenario building, the step 4 using morphological analysis can develop scenarios more flexible manner. Therefore, the proposed approach can combine exploratory and divergent scenarios and goal-oriented TRM more effectively.

Despite the advantages, the paper has limitations and rooms for future works. First, the modeling of weighted TRM can be elaborated to more specific guidelines for exploring factors and putting weights. Second, the development and selection of scenarios can incorporate other criteria such as feasibility, novelty, utility, etc. Lastly, the paper offered only conceptual framework; a case study should be conducted for the firm in high level of uncertainty.

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