Two-phase Cognitive Modeling Methodology for Organizational Learning

Kee-Young Kwahk, Young-Gul Kim
Graduate School of Management, KAIST
kykwahk@samsung.co.kr, ygkim@msd.kaist.ac.kr

Abstract

There is a growing tendency to consider organizational learning as a trait of successful organizations and the rate at which organizations learn is perceived as a source of competitive advantage. In this research, we introduce a Two-phase Cognitive Modeling (TCM) methodology to support organizational learning based on the extended cognitive map concepts. Under the TCM methodology, an organizational learning process is divided into two phases: knowledge share and behavior change. Knowledge share phase emphasizes the understanding of an existing organizational context, while behavior change phase focuses on the significant organizational restructuring. We describe how the TCM methodology can be used in a real-world context, using a tool, called Two-phase Cognitive Modeling Facility (TCMF), developed to support the methodology.

Ⅰ. Introduction

As organizations struggle to reshape themselves to cope with the rapidly changing external environment, interests in organizational learning have been growing. Organizational learning is considered as a core mechanism for improving organizations [Robey, Wishart, and Rodriguez-Diaz, 1995] and the rate at which organizations learn is perceived as a source of their competitive advantage [Stata, 1989; Senge, 1990; Edmondson and Moingeon, 1996]. While several recent surveys identified organizational learning as a critical information systems issue [Brancheau and Wetherbe, 1987; Brancheau, Janz, and Wetherbe, 1996], very few addressed the methodology side of organizational learning. One such issue every organization struggles with is how to model the organizational learning context appropriately. Unlike other IS domains with powerful and elegant modeling methodologies (for example, entity-relationship modeling in database, data flow diagram in systems analysis and design), organizational learning domain does not seem to have such modeling methodology to support it in a systematic way. Another issue is that most discussions on organizational learning do not provide a framework for action [Garvin, 1993]. Their focus is too abstract, and involves various metaphors rather than guidelines for practice. Consequently, they do not specify what concrete changes in behavior are required for accelerating organizational learning. This research introduces a two-phase cognitive modeling (TCM) methodology designed to support organizational learning from the organizational behavior perspective, based on the extended cognitive map concepts. To support the methodology, we developed a tool, called two-phase cognitive modeling facility (TCMF). This tool enhances applicability and practicability of TCM methodology.

Ⅱ. Conceptual Framework

In this section, we discuss the four elements relevant to our study: 1) organizational learning, 2) cognitive modeling, 3) systems thinking, and 4) cognitive map.

2.1 Organizational Learning

Organizational learning has been studied and defined for a long time by numerous researchers and most of them seem to relate organizational learning with knowledge share (including knowledge creation, acquisition, and transfer) or behavior change [Argyris and Schon, 1978; Duncan and Weiss, 1979; Fiol and Lyles, 1985; Stata, 1989; Senge, 1990; Huber, 1991; Lee, Courtney, and O'Keefe, 1992; Garvin, 1993; Edmondson and Moingeon, 1996]. However, either knowledge share or behavior change cannot by itself trigger organizational learning. Without knowledge share, organizations simply repeat old behaviors. In the absence of behavior change, newly shared knowledge becomes futile. Hence, it is essential to consider both aspects for complete organizational learning. In this research, an organizational learning process is divided into two phases: knowledge share and behavior change.

Knowledge share phase involves the creation of knowledge, the acquisition of knowledge, and the transfer of knowledge among organizational members that enables them to enhance organization's efficiency, and emphasizes the understanding of an existing organizational context. Through knowledge share, organizational members can extend their thinking scope to the overall organization beyond their own boundary. In turn, this change facilitates cooperative work among members, which leads to a more efficient organization. *Behavior change phase* involves the modification of behaviors among organizational members to enhance organization's effectiveness, and emphasizes the significant organizational restructuring. Based on the shared knowledge and changed ways of thinking, an organization can create a new type of knowledge on how to change its behavior. This knowledge provides opportunities to understand and resolve the agency problem, to assess the risk taking behaviors of members, and to redesign fundamental business processes for a more effective organization.

2.2 Cognitive modeling

We construct models to highlight or emphasize certain critical features of a system, while simultaneously de-emphasizing other less important aspects of the system [Yourdon, 1989]. Process modeling emphasizes process and data modeling focuses on data, whereas cognitive modeling deals with interrelationships among cognitive concepts. Cognitive modeling has received less attention from the practitioners or the researchers than process or data modeling has. Recently, however, as the importance of cause-effect relationships in an organizational context increases, interests in cognitive modeling are growing. An organization can be perceived as a complex network consisting of interrelated causal elements. By modeling the cognitive aspects of an organization, we can easily capture the major interrelationships and patterns within the organization and can improve the systems thinking capability.

2.3 Systems thinking

Duncan and Weiss (1979) defined organizational learning as "the process within an organization by which knowledge about action-outcome relationships and the effects of the environment upon these relationships are developed". This viewpoint can be best described by the "organizational learning cycle" which consists of individual beliefs, individual action, organizational action, and environmental response [March and Olsen, 1975] and has been widely accepted among researchers [Daft and Weick, 1984; Senge, 1990; Lee, Courtney, and O'Keefe, 1992; Edmondson and Moingeon, 1996].

The action-outcome relationships and organizational learning cycle are closely related to systems thinking. Systems thinking is a body of knowledge and a tool to make the full patterns clearer, and to help us see how to change them effectively [Senge, 1990]. Therefore, systems thinking is a conceptual framework for seeing the whole and for seeing the interrelationships or the feedback loops among its elements. In systems thinking every influence can be both cause and effect. This means that changes intended to improve performance in one part of an organization may inflict other part(s) with negative results.

2.4 Cognitive map

Tolman (1948) introduced the term *cognitive map* to the psychology literature in the 1940s. Axelrod (1976) used cognitive maps in the 1970s for representing social science knowledge. According to Zhang et al. (1989), a cognitive-map is "a representation of relationships that are perceived to exist among the attributes and/or concepts of a given environment". Various researchers have named it differently under different contexts: cognitive map, cause map, and influence diagram. The constructs of a cognitive map are node, called causal concept, link, representing causal connection among causal concepts, and value, specifying causal strength of a causal connection. There are three kinds of cognitive maps depending on the representation method of the causal value: the simplest form which has either '+' or '-', a weighted map which has a value in the interval [-1, 1], and a fuzzy map which employs a fuzzy value such as 'more' or 'some' [Lee, Courtney, and O'Keefe, 1992]. We adopted the weighted map representation because it can express the relative strength of causality (unlike the simplest map) and it is convenient to manipulate (unlike the fuzzy map).

Ⅲ. TCM Methodology

Modeling for organizational learning consists of the following two phases: 1) knowledge share and 2) behavior change. Each phase contains three steps respectively.

3.1 Phase 1: Knowledge Share

Phase 1 generates a global cognitive map which provides individual agents with an overall picture for the organization as well as a local cognitive map for each individual agent. The result of this phase is to be used in phase 2 to aim at behavioral changes.

3.1.1 Step 1: Identify Individual Agents

In this research, an agent is defined as an organizational unit which transfers and shares its knowledge with other units through communication. Agents, for example, can be teams, departments or divisions depending on the level of analysis. We identify individual agents in the following sequence: 1) focus on the critical business areas and 2) specify the goal of individual agents.

Critical business areas are areas where organizations have critical problems or opportunities. If an area has a problem, we will identify its cause and solution. If an area has an opportunity, we will find the means to materialize the opportunity. Clarifying the goal of each agent helps the analysts capture the cause-effect relationships among cognitive elements. Because individual agents behave to fulfill their goal, we can view the cognitive map as describing procedures for accomplishing their goal through the cause-effect relationships.

3.1.2 Step 2: Generate Local Cognitive Map for Each Individual Agent

This step generates local cognitive maps for the previously identified agents. Our cognitive map allows diverse concepts such as state-based (for example, sales volume), action-based (for example, marketing activity), or emotion-based (for example, employee satisfaction) concepts. We should try to find as many causal loops as possible. From the systems thinking perspective, every influence can be both cause and effect, thus an action may have consequences that come back to impact itself. Several techniques exist to help specify the causal values of each relationship. The subjective weights of the analysts can be used, and the result of the statistical analysis can be assigned to the relationships.

3.1.3 Step 3: Generate Global Cognitive Map by Combining Each Local Cognitive Map

This step generates a global cognitive map by combining each local cognitive map, which leads to the common view for the problems or opportunities. We assume that the global cognitive map represents the cognitive map of the group agent which is the collection of individual agents. The global cognitive map plays a role as the organizational memory. In order to combine the local cognitive maps, we first identify the common causal concepts between any two local cognitive maps, and link the maps based on these concepts. In turn, the next local cognitive map is joined with the previous result. This way, the combination process continues until all local cognitive maps are exhausted. While the local cognitive maps are being combined into a global cognitive map, various conflicts among the local cognitive maps might arise. These conflicts should be detected and resolved in order to create a complete global cognitive map. Conflicts may occur in all three constructs of the cognitive map: 1) causal concept conflict, 2) causal connection conflict, and 3) causal value conflict. For the resolution of causal value conflicts, we use the Kosko's fuzzy knowledge combination formula because it is theoretically sound and rests entirely on uncertainty (fuzzy or random) intuitions which reflect the cognitive model of an organization closely (Kosko, 1986). During the combination process, new concepts or new connections can be introduced into the global cognitive map, if necessary for describing the overall organizational behavior, along with appropriate causal values assigned. It is also necessary to specify the goal of the group agent. Clarifying the goal of the group agent is helpful to understand the overall organizational behavior that depends on the various cause-effect relationships.

3.2 Phase 2: Behavior Change

In phase 2, we extract the causal impact paths and values based on the global cognitive map. This phase is addressed computationally by an algorithm. In this phase, we identify the opportunities for organizational behavior change.

3.2.1 Step 1: Convert Global Cognitive Map into Global Cognitive Matrix

In this step, we translate all information in the global cognitive map to a form suitable for mathematical analysis. In order to facilitate the analysis, we adopted a matrix representation method. It allows us to perform necessary computations, and provides updatability which is necessary for the repetitive application of an algorithm. The global cognitive map can be transformed into an equivalent matrix form called global cognitive matrix. It represents the direct causal impact between the causal concepts including the causal strength values of the relationships.

Rows and columns of a global cognitive matrix consist of causal concepts in the global cognitive map, and each row and column corresponds to a specific causal concept. Each cell entry of a global cognitive matrix corresponds to a relationship between any two causal concepts, and the value of the cell entry indicates the causal strength of the corresponding relationship. Causal concept i's impact on causal concept j is represented in cell (i, j). In this way, we construct an n X n matrix with u_{ij} as a vale of cell (i, j) ,where n is the number of the causal concepts and u_{ij} is the causal strength value from causal concept i to causal concept j which lies in the interval [-1, 1].

3.2.2 Step 2: Compute Causal Impact Paths and Values

In this step, we compute causal impact paths and values based on the result of the previous step. The previous step deals with the direct causal impact paths and values which are given directly from the global cognitive map, whereas the current step reveals the causal impact paths with the maximum causal impact values regardless of the direct impact or the indirect impact. These causal impact paths may take negative values or positive values or both, depending on the causal values consisting of the feedback loops.

In order to compute the causal impact paths and values, we adopted the algorithms proposed by Zhang et al. [Zhang, Chen, and Bezdek, 1989], and partially modified them to compute the paths and values simultaneously. At the end of step 2, we get an n X n global cognitive matrix consisting of X_{ij}, where X_{ij} is a set of $\{+p_{ij}, -p_{ij}, +v_{ij}, -v_{ij}\}$. Each element of the set is as follows: $+p_{ij}$ is a positive causal impact path, $-p_{ij}$ is a negative causal impact path, $+v_{ij}$ is a maximum positive causal impact value, and $-v_{ij}$ is a maximum negative causal impact value from causal concept i to causal concept j.

3.2.3 Step 3: Analyze Causal Impact Paths and Values

The objective of this step is to analyze the causal impact paths and values, and to identify opportunities for organizational behavior change. In this paper, we look into opportunities that can be identified from the agency problem, risk taking, and process redesign perspectives.

Agency problem perspective

Most of the organizations consist of various agents which have their own goals. These agents (for example, marketing department) act on behalf of the principal (for example, the organization itself). Agency theory deals with the agency relationship, in which one party (the principal) delegates work to another (the agent) who performs that work. Agency theory is concerned with resolving the agency problem that may occur in the agency relationship. Agency problem occurs when two parties (the principal and the agent) have different goals and it is difficult or expensive for the principal to verify what the agent is actually doing [Eisenhardt, 1989]. The problem is that the agent may take different actions from the principal because of the different goals. Agency problem can be also extended to the relationship between agents as well as the relationship between the principal and the agent.

Different actions within the organization due to the goal conflicts between multiple agents may lead to overall organizational ineffectiveness. Accordingly, agency problem should be considered as a factor for organizational effectiveness and it is necessary to understand and resolve the problem in order to enhance the learning capability of the organization. Because each agent strives to accomplish its own goal, the goal conflicts between agents and between the agent and principal may occur. If these conflicts are not detected and resolved appropriately, it may result in performance degradation for the overall organization while local performance may be acceptable. As a result, it is necessary to coordinate or control the behaviors of various agents based on the identified conflicts.

Risk taking perspective

From the result of the causal impact paths and values, we may identify an opportunity to modify the agents' behaviors depending on their perceptions for the risk. The causal impact paths may take both positive and negative impact values rather than only positive or only negative impact value because of the effect of the feedback loops. Therefore, we can analyze both positive and negative side of agents' behavior for accomplishing their goals. Because of the duality of the causal impact path, agents can modify their behaviors according to the degree of risk taking. For the two alternatives to accomplish the same goal, a risk averter tends to select an alternative with less negative impact, while a risk taker is inclined to take an alternative with more positive impact.

Process redesign perspective

We can also find an opportunity to modify the agents' behaviors, which leads to the redesign of the existing organizational process. We first focus on the most effective causal concept in achieving the goal regardless of the sign of the impact. It can be an opportunity when it is a positive impact, but it can be a problem when it is a negative impact. After this, we can modify behaviors based on the relevant connections or feedback loops so as to make the positive impact stronger and the negative impact weaker. Modification of the organizational behavior can be performed in two ways. First, the modification can be conducted through the generation of the new feedback loops. These loops can also be generated by adding new causal concepts or by inserting new causal connections into the existing global cognitive map. Second, elimination of the undesirable feedback loops from the existing global cognitive map may lead us to modification. This includes elimination of the undesirable causal connections and elimination of the unnecessary causal concepts. These modifications may lead to the redesign of the existing organizational processes. Generation of the new feedback loops means that a new business process is applied to the organizational context. Elimination of the undesirable feedback loops means that the existing process is changed in the organizational context.

Ⅳ. TCMF: A Tool to Support TCM Methodology

Two-phase Cognitive Modeling Facility (TCMF) has been implemented using the Microsoft Visual Basic version 4.0 in the Windows 95 environment. TCMF has been designed as a tool to support our TCM methodology. It consists of five subsystems. Figure 1 shows the overall architecture of TCMF.

Local Cognitive Map Acquisition Subsystem

Local cognitive map acquisition subsystem plays a basic role in TCMF. It supports the step 1 and step 2 of the knowledge share phase (Phase 1) of TCM methodology. It stores agents' cognitive maps in the form of a diagram. A thesaurus is used to determine a causal concept name and to avoid the causal concept conflict. Agents' goals are set through the goal setting window and causal values are specified to causal connections through the causal value setting window in the interval of [-1,1].

Global Cognitive Map Generation Subsystem

Global cognitive map generation subsystem provides a synthesized map by combining local cognitive maps. It takes charge of the step 3 of the knowledge share phase (Phase 1) of TCM methodology along with the conflict resolution subsystem. Local goals are automatically extracted from the participant agents. Conflicts between agents are handled by the conflict resolution subsystem.

Conflict Resolution Subsystem

Conflict resolution subsystem interacts with the global cognitive map generation subsystem. When conflicts occur during the generation of a global cognitive map, the conflict resolution subsystem returns a resolved solution to the global cognitive map generation subsystem.

Causal Impact Path and Value Generation Subsystem

Causal impact path and value generation subsystem provides a matrix which describes causal impact paths and values between causal concepts. It undertakes the step 1 and step 2 of the behavior change phase (Phase 2) of TCM methodology. It stores the causal impact results in the matrix form. The matrix is used by the organizational behavior analysis subsystem.

Organizational Behavior Analysis Subsystem

Organizational behavior analysis subsystem deals with three different issues: agency problem, risk taking, and process redesign. It corresponds to the step 3 of the behavior change phase (Phase 2) of TCM methodology. It analyzes organizational behavior based on information from the causal impact path and value generation subsystem.

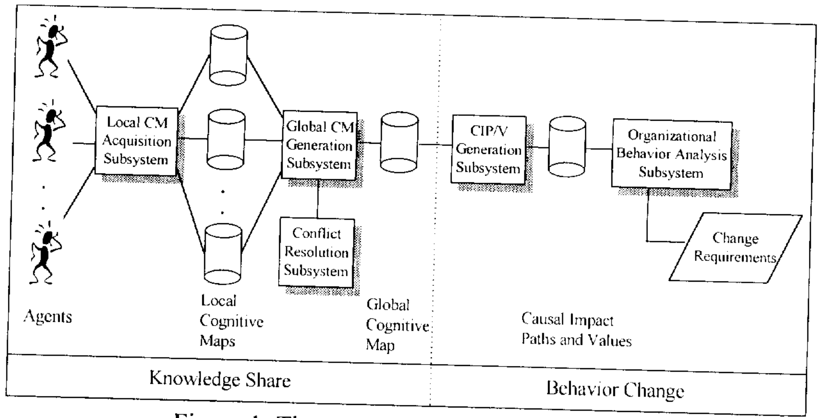

Figure 1. The overall architecture of TCMF

V. Application

In this section, we use a virtual but realistic organization to illustrate our methodology. We assume that the organization is a medium-sized company in the manufacturing industry. Marketing, production, and R&D functions play an important role in a manufacturing firm. Accordingly, we selected the three functions as the critical business areas for improving organizational performance. We define marketing agent as marketing department, production agent as production department, and R&D agent as R&D department.

In order to generate the local cognitive map for marketing, production, and R&D agents, we need to identify the relevant causal concepts for each agent. We identified five causal concepts for the marketing agent such as 'sales volume', 'sales price', 'market share', 'product quality', and 'marketing activity', while we found five causal concepts for the production agent such as 'production volume', 'oversupply', 'sales price', 'sales volume', and 'equipment investment'. For the R&D agent, we also identified four causal concepts such as 'product quality', 'equipment investment', 'R&D activity', and 'management burden'. Then, we identified the causal connections among the causal concepts, and specified the weighted causal values to each causal connection. We assume that the goal of the marketing agent is 'increase sales volume', the goal of the production agent is 'increase production volume', and the goal of the R&D agent is 'improve product quality'. The result appears in Figure 2.

To generate a global cognitive map including marketing, production, and R&D agents, TCMF first tries to identify conflicts among the agents. Conflict resolution subsystem found a causal value conflict between the marketing agent and the production agent. For the impact of 'sales price' on 'sales volume', the marketing agent considered '-0.7' as the causal strength value, while the production agent assigned '-0.9'. Conflict resolution subsystem resolved this conflict using the Kosco's knowledge combination formula. Combined causal value resulted in '-0.8'. After conflict resolution, global cognitive map generation subsystem identifies the common causal concepts among the agents to generate the global cognitive map. It finds the common causal concepts: 'sales volume' and 'sales price' in marketing and production agents, 'product quality' in marketing and R&D agents, and 'equipment investment' in production and R&D agents. By using these common causal concepts to link the three local cognitive maps, the global cognitive map generation subsystem produces a global cognitive map. This global cognitive map provides the three agents with a combined organizational view. At this time we decide to introduce a new causal concept, 'profit', into the global cognitive map along with appropriate connections and values. This causal concept was initially ignored by the three agents, but it is necessary to describe the overall organizational behavior properly. Finally, we specify the goal of the group agent as 'increase profit'. The result appears in Figure 2.

Causal impact path and value generation subsystem computes the causal impact paths and values among eleven causal concepts. Derived matrix includes the negative path and value as well as the positive path and value for each relationship among the causal concepts. The result appears in Table 1 and Figure 3. Based on the result of the causal impact path and value generation subsystem, we can analyze organizational behavior through the organizational behavior analysis subsystem. It deals with three different issues: agency problem, risk taking, and process redesign. First, we can address the agency problem by identifying the goal conflicts between agents. Goal conflicts can be captured by analyzing the causal impact paths. For the production agent and the group agent, efforts for accomplishing the production agent's goal (increase production volume) may lead to failure of the group agent's goal (increase profit) due to increase of oversupply rate and decrease of sales price (refer to Table 1). As a result, it is necessary to control or coordinate the conflict path to avoid failure of the group agent's goal. This way, for each agent, we can identify possible conflict paths, and based on these paths we can coordinate or control agents' behaviors so as to minimize the impact of a conflict. Secondly, we can analyze the agent's behavior depending on the degree of risk taking. The group agent's goal, 'increase profit', can be achieved by the two most positive impact concepts, 'product quality' and 'sales price' (refer to Table 1). However, they have negative impact paths and values as well as positive impact paths and values for the goal. The goal can not always be accomplished through these two concepts because of the existence of indirect negative impact. Therefore, the group agent can modify its behavior for achieving its goal according to its perception of the risk. If it decides to take a position of the risk averter, it may consider 'product quality' as a driver for achieving the goal, and based on the driver it will try to improve the path toward the goal. On the other hand, if it chooses to take a position of risk taker, it will select 'sales price' as a driver for achieving the goal, and based on the driver it will try to improve the path toward the goal. In addition to this, these causal impact paths and values can be used in redesigning the related areas including marketing, production, and R&D functions. In order to find the redesign opportunities for the group agent, we focus on the most effective causal concept in achieving the profit increase (refer to Table 1). From Table 1, we identify two effective causal concepts. One is 'sales price' which is the most positive causal concept (causal value is '+0.900'), and can be considered as an opportunity. The other is 'oversupply' which is the most negative causal concept (causal value is '-0.810'), and can be viewed as a problem. Naturally, our objective is to make 'sales price' feedback loop stronger and to make 'oversupply' feedback loop weaker. For the 'sales price' causal concept, this means making the positive loop more positive and making the negative loop less negative. For the 'oversupply' causal concept, this means making the positive loop less positive and making the negative loop more negative. We can modify the related feedback loops or connections according to these objectives through generating new feedback loops or eliminating existing causal connections and concepts. In turn, we can redesign the organizational process related with the modified feedback loops. The analysis is shown in Figure 3.

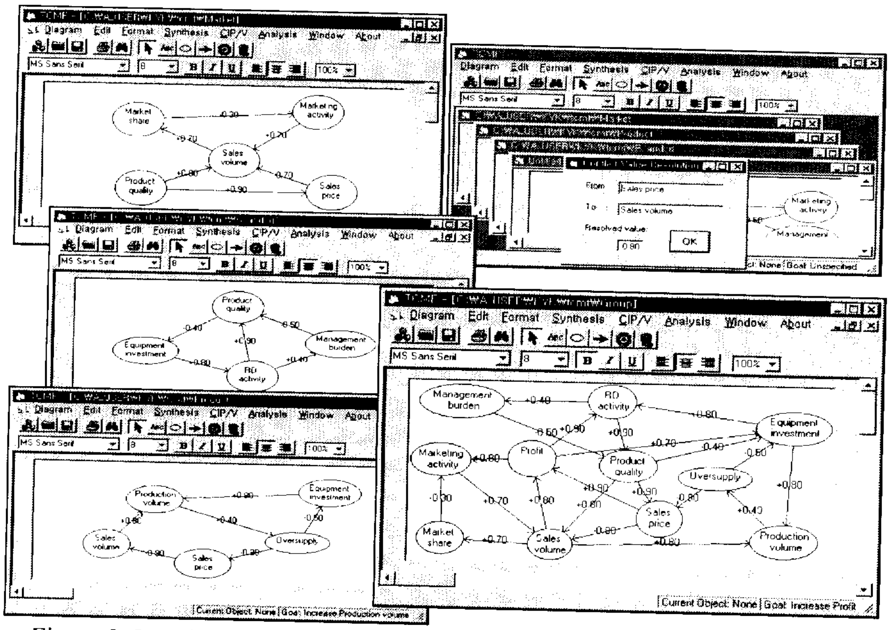

Figure 2. Local cognitive maps, conflict resolution, and global cognitive map

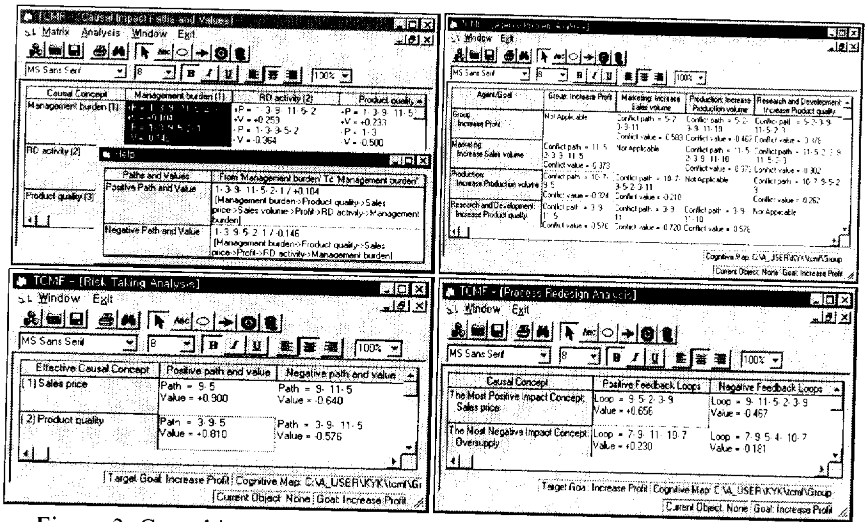

Figure 3. Causal impact paths/values and organizational behavior analysis

VI. Conclusion and Future Directions

We proposed a methodology to generate a model for organizational learning based on the cognitive map concepts. We divided an organizational learning process into two phases: knowledge share and behavior change. *Knowledge share* emphasizes the understanding of an existing organizational context, while *behavior change* focuses on the organizational behavior change and may require significant organizational restructuring. Combining these phases, we presented a two-phase cognitive modeling (TCM) methodology and described how the modeling result can be used in a real-world organizational learning context. We designed and implemented a tool, called two-phase cognitive modeling facility (TCMF), to support TCM methodology.

The contributions of this research are as follows. First, we provided a systematic modeling methodology to support an organizational learning process. For rigorous as well as user-friendly modeling, we adopted the mathematical approach based on matrix manipulation and the graphical approach using diagrams. Second, we specified what concrete changes in behavior are required for accelerating organizational learning. This leads to seeing the enterprise reality in a new way and taking an action accordingly. Third, we implemented a tool with graphical interface. This enhances applicability and practicability of our methodology.

Currently, however, there are several limitations in the methodology. First, it is hard to obtain valid causal values. Although this research suggests several techniques, this issue still remains as a limitation. Second, TCM methodology does not consider the cause-effect relationships with time delay among causal concepts. A causal concept might affect other one with time delay. Third, this paper addresses only three types of behavioral change. However, there can be other significant types of changes as well.

One of the future directions of this research is to include time dimension in the methodology and to represent time delay among interrelated causal concepts. Another direction is to extend our modeling methodology into the areas of integrated process and data modeling since the cognitive model can play a role as a complement for the other two enterprise modeling techniques.

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