Building Knowledge Based Simulator for Ill-Structured Dynamic Domain Using Cognitive Map : An Application to Stock Market Prediction

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1. Introduction

Building knowledge based systems for the stock investment decision making is a very challenging issue. However, this domain has some characteristics that make it difficult to tackle because the nature of stock market is probabilistic and situational. The factors affecting stock market are not well defined and the influences between them are unstable. There are so many theories, techniques and approaches to stock market in proportion to the difficulty of stock market prediction.

Even though the task is not so easy, stock investors are now making their analysis and decisions in the stock market, and the investment experts explain the current stock market in the newspaper column. They use their own experience, rule of thumb, insight and subjective judgment. Needless to say, their decisions are not so correct. Because human's capability of synthesize all relevant factors and influences is very limited and tends to be ad hoc and error prone.

To overcome such human's limitation and to construct decision supporting systems or expert systems for such a ill-structured domain as stock market, the knowledge building and representation method should be capable of analyzing and constructing the structure of the domain and inferencing the knowledge. It also have to capture the insight and experience of decision makers and interconnection of factors and variables in the domain.

The rule-based knowledge representation is not fitted for the domain. The type of interconnection of rules is tree. Tree is prone to be inconsistent redundant, conflict and can not handle cycle. Furthermore, the credibility or uncertainty of rules is hard to be quantified.

We suggest another approach using *Cognitive Map* introduced by Axelrod[1976]. It can figure out the domain by unrestricted network of causal and effect. It also has dynamic nature. The network system state evolves over time along the causal-effect relationship of nodes in the network. So we can simulate the change of states as time goes.

We tested the usefulness of cognitive map: whether it is easy and rapid to build knowledge, capable of representing dynamic and unstable structure and subjectiveness of decision maker.

The main motive of our approach is to accept the decision maker's cognitive judgment about the complex decision environment rather than to remove it. In the ill-structured domain, it would be better respect human's judgment from experience if we could not develop alternative models or algorithms to override human. By supporting human's weak point - limitation of memory and error prone - the insight of human to the domain may be maximally utilized.

2. Knowledge in Ill-Structured Dynamic Domain.

The characteristics of ill-structured dynamic domain are : First, it's structure is unstable, that is the status of factors and influences between the factors change over time. It is not the same with the automatic assembling factory where the input-output relationship is not changed during their operation. Second, the factors are not well defined. It is impossible to construct all relevant factors affecting the domain. Third, normative methods such as theory, algorithm, model are not operating sufficiently to settle down the problem. For stock market domain, there were neural network model to predict stock price and inductive learning algorithm, and financial theories and models. However, they could not perform in stock market prediction as much as to be usually used by investors society. Fourth, the human experts have their own knowledge, but it is hard to formalize the knowledge and human can grip only a fraction of overall domain because the knowledge is very subjective and cognitive depending on their experience.

To capture the such knowledge, the knowledge representation method should have flexibility, that is, any sub component of knowledge can be deleted and modified or new one can be added. Second, it should handle cycle of relationship between factors. Third, multiple experts can combine their knowledge into a unified one. Fourth, we can simulate the change of each state of factor in the knowledge to see what will happen at the next stage in the dynamic domain.

3. Cognitive Map

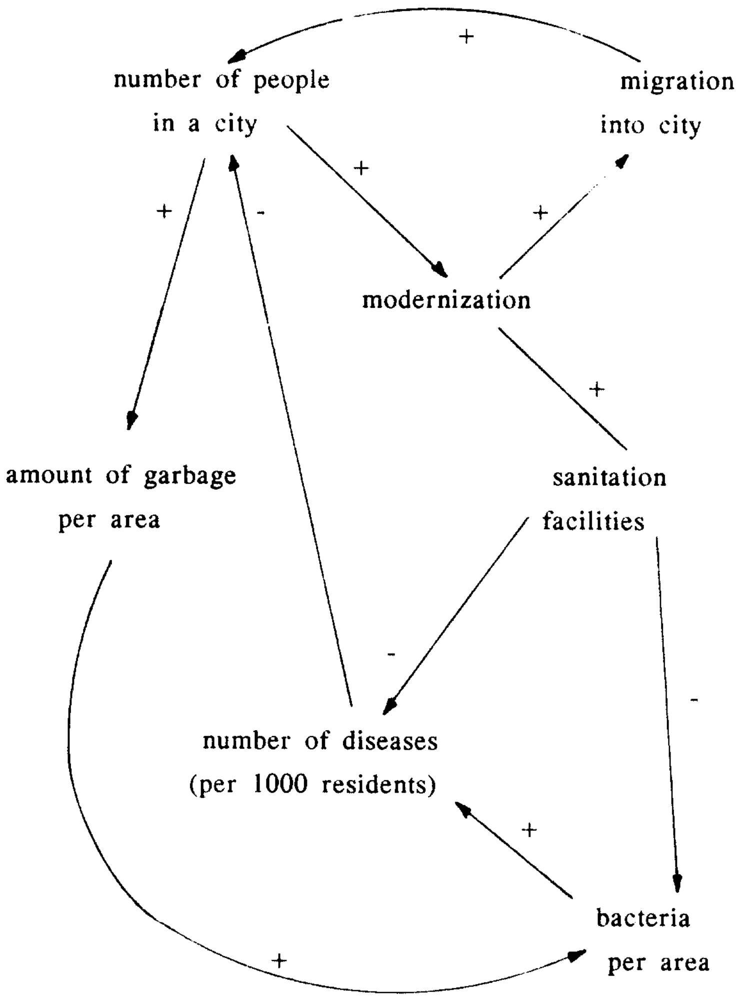
A cognitive map is a representation of the relationship which are perceived to exist among the factors of a given environment. Taking any two of these factors, the concern is whether the state or movement of one is perceived to have an influence on the state or movement of the other. The link between two factors are cause and effect relationship. One factor cause the other to be affected. The links are determined by a person's mental and cognitive knowledge. The knowledge is acquired through observation and experience or education. The cause-effect relationship is categorized into positive and negative relationship. For instance, in Figure 1, if sanitation facilities were improved, the incidence of disease would decrease. However, better sanitation facilities, causing in initial improvement in health, would lead to an increase in the city's population. In turn, this growth might lead more garbage, more bacteria, and therefore, more diseases, thereby overcoming the initial advantage of improvements in sanitation [Montazemi and Conrath, 1986].

More complex cause and effect relations rather than simple positive and negative is possible. The Fuzzy Cognitive Map(FCM) introduced by Kosko[1987] uses fuzzy value between -1 and 1 to represent the degrees of relationships.

The principal reasons for developing a cognitive map in specific applications are:

(1) To obtain insight into the structure of the decision environment that might be difficult to obtain otherwise.

Figure 1. Cognitive Map for Director of Public Health.
From Montazemi and Conrath (1986).



(2) To provide a means, at a minimum, for gathering information about a decision environment that enhances our understanding of it.

(3) To gain insight regarding the relative information value of the various factors involved.

Therefore, a cognitive map can be used as in the following manner: (1) identification of irrelevant data in an information systems, (2) detection of new factors relevant to a specific decision, and (3) alternative to knowledge engineering, that is, construction of causal knowledge base capable of yielding chains of influence against the shock of changes of a particular environmental factor [Taber, 1991].

A cognitive map can be developed in line with the following steps:

(1) To construct a cognitive map, it is important to start with clarifying the purpose for which the cognitive map is being built. If the purpose is not well defined, the search for relevant factors is likely to lack direction and the cognitive map might easily grow to an unmanageable size.

(2) Identify the relevant factors, those which may influence a decision and can vary in their values.

(3) Find causal relationships among factors identified in step 2. The ways of determining these are either to derive from decision makers' statements [Axelrod, 1976; Eden, Jones, and Sims, 1979] or to use questionnaires structured specifically for this purpose[Montazemi and Conrath, 1986].

(4) Derive cognitive map matrix. The rows are the factors of the domain. So are columns. The entry at i,j of the matrix are +1 (positive cause and effect relationship), 0 (no cause and effect relationship), and -1 (negative cause and effect relationship).

The cognitive map is easy to use and develop. However, it is worthwhile to clarify some points to avoid confuse in drawing a cognitive map.

(P1) The effect ($A \longrightarrow B$) is not necessarily the same as ($B \longrightarrow A$). So the cognitive map matrix is asymmetric square matrix.

(P2) $A \xrightarrow{+} B$ means that if the degree(value) of factor A is high then the degree(value) of factor B becomes high.

(P3) $A \xrightarrow{-} B$ means if the degree(value) of factor A is high then the degree(value) of factor B becomes low.

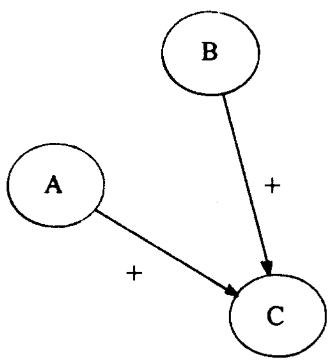
(P4) If $A \xrightarrow{+} B$, then $\sim A \xrightarrow{-} B$, where $\sim A$ means not A.

(P5) If $A \xrightarrow{-} B$, then $\sim A \xrightarrow{+} B$, where $\sim A$ means not A.

The example of P4 is : If we assume that vehicle speed $\xrightarrow{+}$ accident rate, it means that if vehicle speed is high, then the accident rate is high. It also means reversely that if vehicle speed is low(the reverse concept of high vehicle speed), then the accident rate is becomes low.

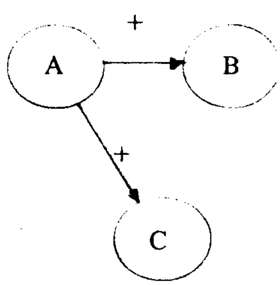
The initial cognitive map must be tested by simulation if there were some inconsistency. The inconsistency in cause and effect relationship can be illustrated as following example. If factor C was related positively with both factors A and B as in Figure 2, and the values for the A and B were both high, the value of C would be expected to be high as well. If it were low, it is inconsistency. The reason why the cognitive map does not behave as we perceive is that some other factors are affecting C in the negative direction. Therefore the hidden factors that were not originally thought to be relevant ought to be considered.

Figure 2. Example of a Cognitive Map



The cognitive map dynamically evolves. The status of each factors are affected through the connected links. The transition from one state to another is simulated by cognitive map matrix. The matrix is excited by a vector of inputs. Excitation is vector-matrix multiplication. The input vector is ordered status of factors. For n factors, the input vector is 1 by n. The output vector produced by multiplying the input vector by n by n cognitive map matrix is the consequential status of factors excited by antecedent status of factors. For example, if a simple cognitive map matrix is as in Figure 3, the factor A can excite B and C at next transition stage. The input vector is (1 0 0) and the output vector is (0 1 1).

Figure 3. Dynamic State Change by Vector-Matrix Multiplication



	A	B	C
A	0	1	1
B	0	0	0
C	0	0	0

$$[1\ 0\ 0]\begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} = [0\ 1\ 1]$$

The output vector can repeatedly become the next input vector for further transition. However, the element of output vector can be either higher than 1 or lower than -1, since each output element results from n multiply/accumulate operations[1]. However,

1) Consider when the cognitive map matrix is $\begin{bmatrix} 0 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ in Figure 3.

because we do not give subtle interpretation of the degree of a factor more than +1, -1 and zero, 2 or -2 is not interpreted as doubly high or doubly low. Nonzero elements indicate only that the factor does occur given the antecedents. Therefore, a truncation operation is required. An element is truncated into +1 if it is more than +1 and truncated into -1 if it is lower than -1. Zero remains zero.

4. Building Cognitive Map on Stock Market

For the stock market, there are abundant source of knowledge. Pamphlets issued by security companies, magazines and newspapers that explains current situation and future expectation of stock market behavior are scattered around us. We can easily build a initial knowledge base if we trace the past stock market guided by the back issues of above materials. The materials explains well why the on-going situation of stock market occurs. The relevant factors and its causal relationship between others can be acquired if we analyze the explanation of the material why the stock price has increased or decreased. Also we can interview with experts or distribute questionaires to attain consensus about the factors and their relationships.

The purpose of our cognitive map is to predict composite stock price change. The composite stock price is determined by the supply and demand of stocks. The supply is the selling of stocks possessed by individual investors or institutional investors such as bank, insurance company, investment trust company, securities company, credit union, various funds, and company's going public by listing on the stock market. The demand is the purchase of stocks by individual and institutional investors.

We have constructed a cognitive map for composite stock price prediction as in Figure 4 and the cognitive map matrix is as in Figure 5.

5. Simulation Example

We can simulate the cognitive map by giving a input assuming some situation of stock market. If the government announced a stock market supporting policy, and the composite stock price has renewed the lowest level of stock price in the year, the institute investors will start to purchase stocks and the investing population recognize the current stock price is in the ground level, and the investment psychology becomes to be improved at the next stage. The recognition of ground level make the

Figure 4. A Cognitive Map for Composite Stock Price Prediction

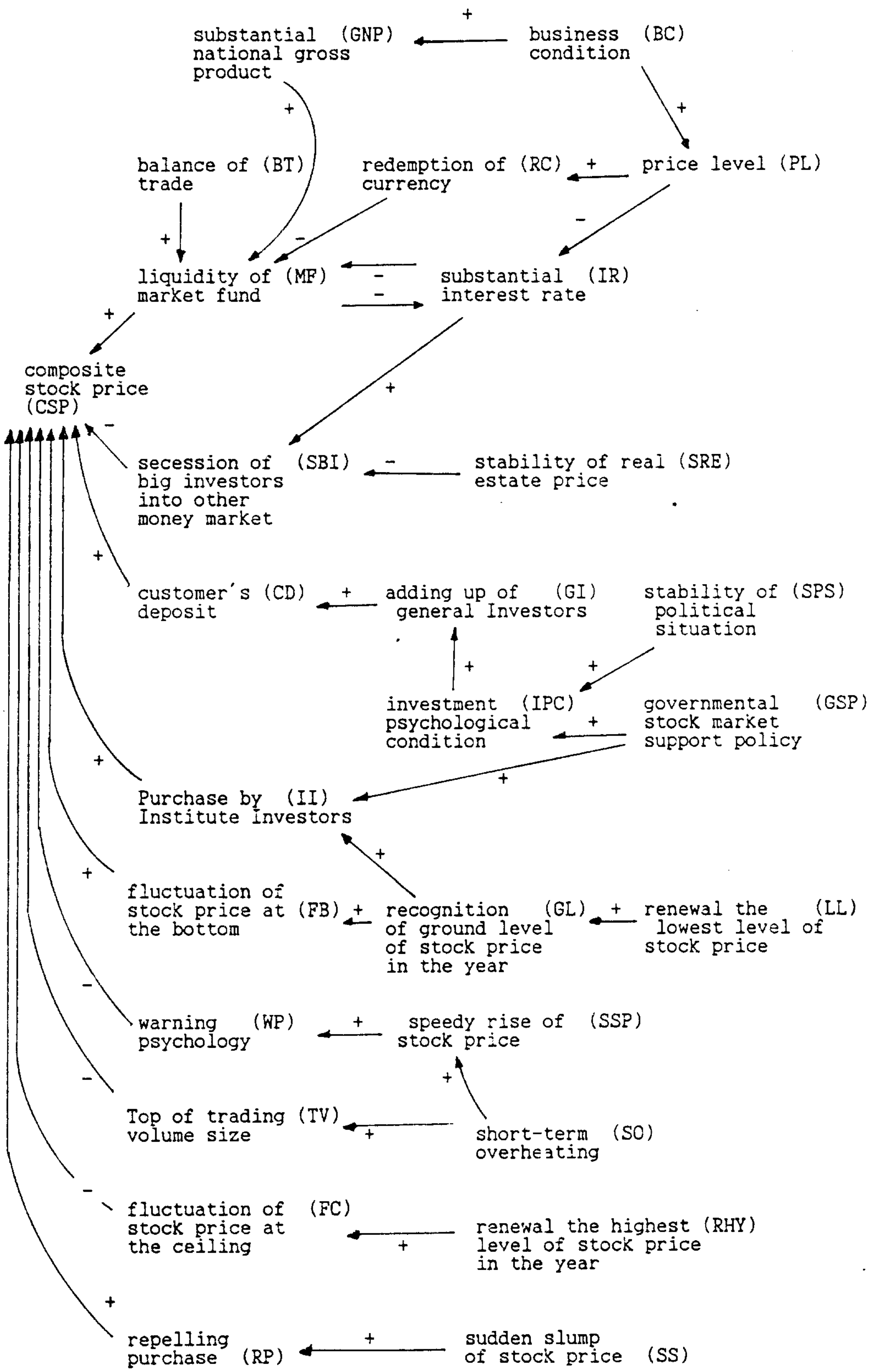


Figure 5. A Cognitive Map Matrix for Composite Stock Price Prediction

	CSP	GNP	BC	BT	RC	PL	MF	IR	SBI	SRE	CD	GI	SPS	IPC	GSP	II	FB	GL	LL	WP	SSP	TV	SO	FC	RHY	RP	SS
CSP																											
GNP							+1																				
BC		+1				+1																					
BT							+1																				
RC						−1																					
PL					+1			−1																			
MF	+1							−1																			
IR						−1			+1																		
SBI	−1																										
SRE									−1																		
CD	+1																										
GI											+1																
SPS														+1													
IPC												+1															
GSP														+1		+1											
II	+1																										
FB	+1																										
GL																+1	+1										
LL																		+1									
WP	−1																										
SSP																				+1							
TV	−1																										
SO																					+1	+1					
FC	−1																										
RHY																								+1			
RP	+1																										
SS																										+1	

institutional investors purchase more stocks and this lead to increase of the composite stock price. General investors also begin to purchase stocks, therefore the amount of customer's deposit becomes grow. The increase of customer's deposit cause more stock price increase. This process can be illustrated by matrix multiplication form as in Figure 6. If the initial input vector is V_1, where the element that corresponds to GSP and LL are 1 and the others are all 0. The output vector V_2 represents the next stage of situation produced by V1 x M, where M is the cognitive map matrix. The V_2 is the vector where the elements corresponding IPC, II, GL are 1 and the others are all 0. V_2 can be repeatedly the next input vector producing V_3 by V_2 x M. This process can be repeated until we figure out how the stock price will behave. In this case, we can predict that the composite stock price will increase. During simulation, we also can reflect new situation by modifying the next input vector. What we have to be cautious in simulation is that if real world is different from the output vector, the next input vector should be adjusted reflecting the real situation. For example, if the GL(recognition of ground level of stock price in the year) does not occur yet in real situation after the first transition, the GL of vector V_2 should be zero to be used as the input vector at the next transition.

Figure 6. An Simulation Example

V_1 = (0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0)

: GSP = 1, LL = 1

V_2 = V_1 x M

= (0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0)

: IPC = 1, II = 1, GL = 1

V_3 = V_2 x M

= (1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0)

: CSP = 1, GI = 1, II = 1

V_4 = V_3 x M

= (1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0)

: CSP = 1, CD = 1

V_5 = V_4 x M

= (1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0)

: CSP = 1

V_6 = V_5 x M

= (0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0)

: All factors are returned to the initial status waiting for the next stimuli.

6. Soundness of Cognitive Map

The cognitive map is a useful tool to capture the complex and dynamic domain. However, the cognitive map must pass a test with following question : Is it sound? The question means that whether the cognitive map can represent what it will represent without incorrect interpretation and without any trouble. The first doubt of soundness is *concurrence conflict*. Assume that two factors A and B are both causing C as in Figure 2. If A is high and B is low, then what is the value of C? The high A cause the value of C to increase by P2 while low B cause the value of C to decrease by P4. If we did not know which cause is stronger, it's vague how to determine the value of C. The conflict can be resolved by using fuzzy cognitive maps which use fuzzy value to represent a degree of relationship. However, fuzzy cognitive map give us a heavy problem : determining the fuzzy values and what is more, keeping the consistency of fuzzy values on overall cognitive map. The concurrence conflict can be extended more than two antecedent causal factors. For example, which direction can the composite stock price move if SBI(secession of big investors into other money market) occurs, CD(customer's deposit) increases and II(purchase by institute investors) progresses?

A conflict resolution method is to rank the causal factors according to the degree of impact. The ranking between causal factors on one caused factor is relatively easier than ranking all the relationship on overall map. This is a local ranking between adjacent factors which have the same caused factor. If there occurs conflict, conclusion is derived by following the highest ranked factor's status in the conflict set (in above example, conflict set is {SBI,CD,II}). We can revise the cognitive map by annotating rank to the multiple causal factors on one caused factor. In the ranking method, one highly ranked factor have the power over other lowly ranked factors regardless of the numbers. This can be illustrated as one honest man is enough than hundreds of liars.

The second doubt is that length of causal link may be interpreted as navigation length. For example, BC(business condition) causes CSP(composite stock price) via GNP (substantial national gross product), BT(balance of trade) and MF(liquidity of market fund) while SRE(stability of real estate price) causes CSP via only SBI(secession of big investors into other money market). Assume that SRE gets high value (real estate price gets stable) and BC has low value (business condition is bad). What is the direction of CSP ? Is it really true that CSP will increase via the shortest causal path from SRE and then decrease because of BC ? Consider the counter example assuming that we have built the cognitive map neglecting the intermediate steps GNP, BT and MF. In the case, BC causes CSP directly. Now let's ask the same question : Is it true that CSP will decrease because of low BC and then increase because of SRE via SBI? Cognitive map does not imply that the link between any two factors have the same transition time. Some link require more transition time than others. Consider the links between BC and GNP which requires longer transition time than the link between LL(renewal the lowest level of stock price) and GL(recognition of ground level of stock price in the year). However, more precise cognitive map require us to align every links having the same - at least similar - transition time. Most links having long transition time may have missing intermediate factors. For example, the direct link between BC to CSP requires long transition time because of many intermediate factors were missed. The missing intermediate factors can reduce the impact power of the causal factor to the caused factor. The conflict resolution between concurrent factors can also be achieved by finding missing intermediate factors.

The third doubt is that the properties P4 and P5 may not be satisfied. Consider the relationship between BC(business condition) and PL(price level). When business condition is high(good) then the price level usually increase. However, there may be an economic situation that even though the business condition is low(bad), the PL does not decrease. The situation may be resolved by finding the unknown factors obstructing the decrease of PL. Otherwise, simply modify the factor PL to IPL(increase of price level) by adding the attribute of direction to the factor. Because ~(IPL) does not necessarily mean decrease of price level, P4 can be satisfied.

7. Concluding Remarks

We have shown that the cognitive map can be a simple but useful knowledge building tool in the ill-structured dynamic domain such as stock market. Using cognitive mapping technique, we can improve our understanding of complex decision environments based on simple data collection about pairwise relations. A cognitive map can display the causality between factors and chains of relationships. Cognitive map enable us to simulate interactively the domain how the factors are affected as time goes. Because the cognitive mapping technique is simple and based on decision maker's cognitive knowledge, it enables one to individualize the knowledge based information system. Furthermore, it is flexible to be easily modified. We have examined the soundness of cognitive maps. We found that concurrence conflict, different navigation length and positive/negative discontinuous relationship may cause incorrect interpretation and some trouble. We suggest several resolving methods such as local ranking, transition time alignment and revelation of missing intermediate factors. Simplicity may generate vagueness in dealing with some subtle situation. However, cognitive map must be one of useful tool to capture the complex and dynamic domain.

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