A Simulation Method of Cognitive Maps

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ABSTRACT: *Cognitive maps are widely used for representing decision makers' mental maps and their strategies. However, the cognitive map analysis is usually constrained into the static analyis and has difficulty in exploring dynamic nature of decision makers' mental map. In this paper, a simulation method of cognitve map in the discipline of system dynamics is developed and discussed. In this paper, the concept of abstract simulation is proposed to allow simulation of cognitive maps to see their dynamic behavior without distorting them too much. As a way of abstract simulation, NUMBER is introduced in this paper. NUMBER is an abbreviation for 'Normal Unit Modeling By Elementary Relationships'. In this paper, NUMBER is applied to a cognitive map of policy maker to show its usefulness.*

Keywords: system dynamics, cognitive map, abstract simulation

NEEDS FOR ABSTRACT SIMULATION

In the discipline of system dynamics, causal maps have been used mainly as a bridge between system insights and system modeling (Richardson and Pugh 1981, Roberts et al 1983, Wolstenholme 1990). Recently, the value of a causal map in its own right is rapidly gaining ground (Coyle 1998, 1999). The causal map can be built with less time and efforts than a simulation model and it can give important insights and understanding that clients demand (Colyle 1998, Eden 1988). On the other hand, cognitive map has been used widely to represent mind maps of decision-makers without using computer simulation (Axelrod 1976, Bonham & Shapiro 1986, Weick 1986, Eden 1988, 1994, Jenkins & Johnson 1997). However, the causal map and cognitive map have fundamental limits in understanding behavioral implications. Even the use of fuzzy cognitive maps have their limits in simulation (Kardaras & Karakostas 1999)

By simulation, we tend to think about quantitative and concrete modeling. Simulation implies implicitly the operational model (Richmond 1993). In this narrow sense, causal maps and cognitive maps are far from the model that can be simulated in computer. But we need not confine the concept of simulation into the narrow meaning of quantitative, concrete, operational modeling. People perform mental simulation most of the time without hard models and computers. Also, there have been studies on qualitative simulation as well as quantitative one. Figure 1 shows various ways of simulation with two dimensions: structure-oriented vs. parameter-oriented dimension and dimension of qualitative vs. quantitative simulation.

To build a system dynamics model from a causal or cognitive map, two kinds of task are required. First, one must add some operational structure. Second, lots of quantification should be introduced into the original map. Since these two kinds of task require too much burden, simulation of them are usually given up. However, there often come some situations that one cannot avoid the simulation of the causal or cognitive map. Sometimes system insights can be found only after one sees the dynamic behavior of the causal and cognitive map. When this situation occurs, one has to collect additional data and information to build a system dynamics model. But, more often than not, it is difficult to collect enough data. Usually additional data and complication of the map to make a simulation drives away the original insights. In this paper a concept of 'abstract simulation' is proposed to resolve this dilemma.

In figure 1, one can see how abstract simulation can be a bridge between causal map and SD model. Abstract simulation means a simulation of a model that is built from abstract or conceptual variables and causal relationships. It is different with econometric model or statistical model in that abstract model will be based on the causal relationships among variables presented in the causal map and cognitive map. Abstract simulation provides an environment where one can simulate causal map or cognitive map without requiring additional data on structure and parameters. One can simulate causal map and see their time behavior. However, one cannot simulate the causal map without introducing additional assumptions on structures and parameters. Abstract simulation environment is supposed to provide these assumption automatically. At least, one can have opportunity to systematically experiment with additional assumptions introduced to simulate the causal map.

These features of abstract simulation are required for at least three reasons. First, abstract simulation will help in preserving generic nature of causal map. Sometimes causal map is built with highly abstract variables to maintain its generic nature. For example, causal maps for systems archetype use ultimate abstract variables (Meadows 1982, Kim 1992, Senge 1990). Also when consulting specific companies, highly abstract causal maps will be provided to catch the fundamental insights. Section III of this paper will demonstrate how abstract simulation can preserve the generic nature of systems archetype.

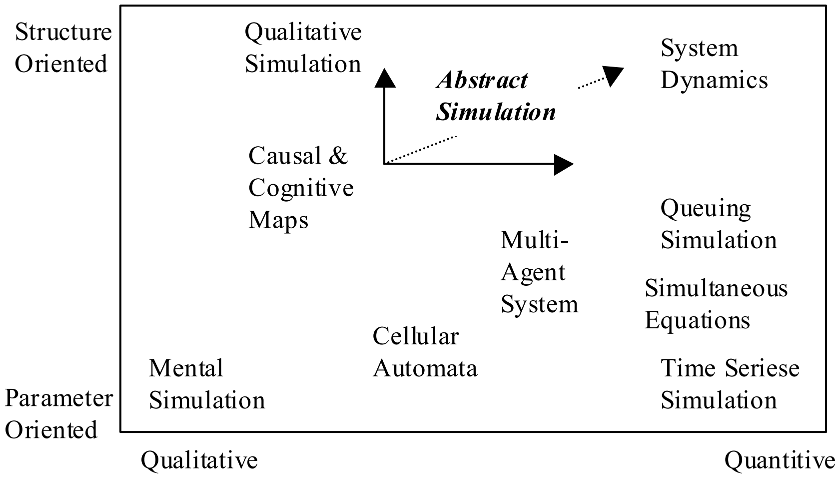

Figure 1. Diverse ways of simulation and Abstract Simulation

Second, abstract simulation is required to preserve the purity of cognitive maps. If one introduces additional assumptions into the cognitive map for simulation purpose, the purity of cognitive map will be destroyed. A simulation model built by researcher will reflect the mind of researcher rather than policy makers from whose statements the cognitive map is built. In this situation, abstract simulation of cognitive map will help in minimizing the number of additional assumptions and will make it clear what additional assumptions are introduced. Third and last, abstract simulation will increase the honesty of system scientists. If one cannot know the concrete structures and parameters, one need not hide his ignorance to build a simulation model. Rather, by using abstract simulation approach, he can simulate without introducing his own assumptions. He can attribute wrong assumptions, if any, to the abstract simulation method and thus he can be more neutral and critical to the assumption. In this way, he can maintain his honesty in simulating the unsimulable mental maps.

NUMBER FOR ABSTRACT SIMULATION

In this study, a method for directly converting cognitive maps is proposed as a way for implementing abstract simulation. This method has been named as 'NUBMER' indicating "Normalized Unit Modeling By Elementary Relationships". The method of the NUBMER has three steps for converting a cognitive map into a SD model. First, several variables in the cognitive map are chosen as level (stock) variables according to their role in the map. Second, all variables are normalized between 0 and 1. That is why this method is called as Normalized Unit Modeling. Thus this method normalizes units of all variables between 0 and 1. In the third and last step, variables are connected by elementary relationships that are designed to constrain the value of variables between 0 and 1. Especially, level variables are connected with automatically introduced rate variables by predefined relationships. Thus this method is called as "normalized unit modeling by elementary relationships (NUMBER)".

NUMBER is consisted of two important assumptions. The first assumption is that the value of all variables can be expressed between 0 and 1. This does not mean that all variables should remain between 0 and 1. Some variables like gap and distance can have minus value. But even the minus value must be remained between 0 and -1. This constraint will allow variables in the acceptable ranges and prohibit them from affecting other variables by extreme degree. One has to notice that addition, subtraction, and division might lead variables to exceed this constraint. But multiplication will preserve variables within this range. With this constraint, there are some safe operations for calculation. Thus with the NUMBER modeling, multiplication is recommended to represent causal relationships.

Table 1 lists typical example of the safe operations. For example, if there is an opposite relationship between two variables A and B, one can represent it as "A=a*(1-B)" instead of "A=a/B". Even though this safe formula cannot cover all kinds of causal relationships, they will provide safe ground to quantify abstract conceptual variables. If one cannot represent some causal relationships, he can use graph function. In addition to this safe formula, an elementary relationship between level variable and rate variables is also introduced in NUMBER. Since the value of level variable is accumulated during the simulation, it will easily move out of the boundary. This elementary relationship is introduced to keep the level variable within the boundary between 0 and 1.

Table 1. Safe operation that will satisfy the constraint of 0 and 1.

Safe formula	Meaings
A = 1- B	B affects A disproportionately.
A = 0 + B	B affects A proportionally.
A = 0.5 + B/5	B affects A proportionally beyond 0.5.
A = (B + C)/2	B and C affects A proportionally.
A = (B - C)/2	B affects A proportionally and C affects A disproportionately.
A = B * C	B and C increase A.
A = B*(1-C)	B increases A but C decreases A.
A = (1-B)*(1-C)	B and C decrease A.

Figure 2 shows the elementary relationship between level and rate variable. In figure 2, the level variable affects its own increasing rate and decreasing rate both directly and indirectly. Indirect feedback loop of the level variable is linked by the variable of changing ratio that represents intervening variables in feedback loops.

level variable = INTEG (increasing rate - decreasing rate)
increasing rate = (1- level variable) * changing ratio
decreasing rate = (level variable) * changing ratio

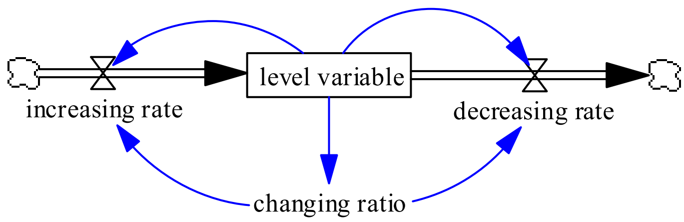

Figure 2. Elementary relationship between level and rate variables

Figure 2 shows equations that will preserve value of the level variable between 0 and 1. In order to ensure this, increasing rate is defined to converge towards zero as the value of the level variable comes near 1. This can be done by multiplying (1- level variable) to the equation of the rate variable. On the other hand, we defined the decreasing rate to converge toward zero as the value of the level variable goes to zero. This can be done by multiplying the level variable to the equation of the decreasing variable. Thus the value of the level variable stops increasing as it comes to 1 and it stops decreasing as it moves to 0. In this way, the level variable remains in the boundary of 0 and 1.

Figure 3 shows how the level variable in the elementary relationship will change with its own elementary feedback loops. One can find that the initial value of the level variable will determine its changing behavior. When its initial value is low, it will grow. But with a high initial value, it will decrease. In addition, the indirect feedback loop affects the time behavior of the level variable. If the equation of changing ratio is defined as '1 - level variable', the time behavior of the level variable shows s-shaped growth.

From the time behavior in figure 3, one can find that the level variable defined in the elementary relationship has a tendency of maintaining equilibrium. In fact all feedback loops in figure 2 are negative loops. The fundamental assumption in the method of NUMBER is that all conceptual variables have a tendency of staying in their own equilibrium. This fundamental stability assumption can be justified on the ground that all conceptual variables are supposed to maintain their current value as long as there is no force to change it. In fact this is a fundamental law from physics. Thus, if there are other forces affecting the level variable, it will change the value of the level variable out of the equilibrium states. Furthermore, this equilibrium itself will be affected by other variables and feedback loops. If other feedback loops are dominant over the elementary relationship, the level variable will run away from the equilibrium and show diverse behavior including fluctuating, growing and decaying. Since the feedback loops of the elementary relationship will have their strongest loop gains only at the extreme point of the level variable at near 0 and 1, other feedback loops can dominate easily the dynamics of the level variable in normal times.

NUMBER is a technical guideline for performing abstract simulation. As discussed above NUMBER consists of two important rules: 1) constraining unit of variables between 0 and 1 and 2) elementary relationship for level variables that will automatically enforce the value of the level variable within the boundary. With NUMBER, one can convert causal map and cognitive map directly into system dynamics model by introducing only some rate variables to make the elementary relationships for level variables. In order to experiment the usefulness of NUMBER, it is applied to a cognitive map of policy maker.

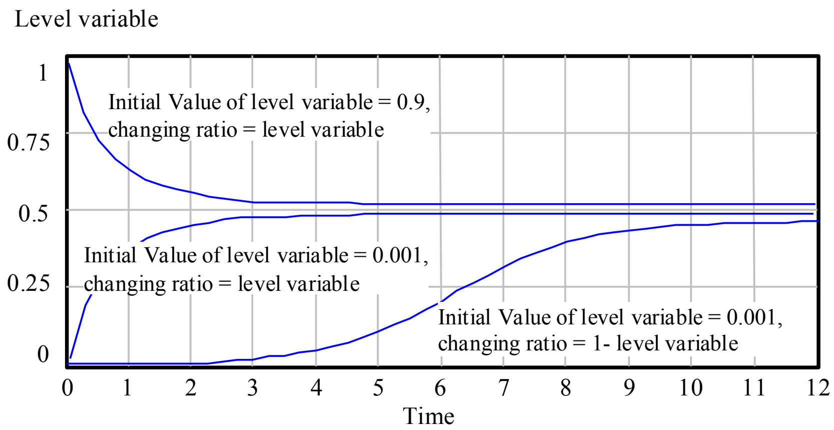

Figure 3. Time behavior of elementary relationship

SIMULATION OF COGNITIVE MAP

NUMBER can be applied to causal maps and cognitive maps. In this section, application of NUMBER to the cognitive map of President of Korea has been demonstrated. The cognitive map of President Kim Dae-Jung is relatively complex. When this cognitive map of President Kim Dae-jung was constructed from his statements for overcoming financial crisis of Korea, a question of "how can you be sure that the cognitive map is sufficient" came across to author’s mind. To reply answer to this question, the author devised the method of NUMBER. If one can simulate cognitive map of policy maker and can get simulation results similar to what the policy maker said, we can say that the cognitive map is sufficient to explain his policy.

Figure 4 is a cognitive map of President Kim Dae-Jung collected from his statements in 1998 (Kim 1999). And figure 5 is a system dynamics model derived by applying NUMBER to the cognitive map of figure 4. Only some important variables that form feedback loops in the cognitive map are included in the system dynamics model of figure 5. When the SD model of figure 5 was simulated, the author was surprised to find that the simulation shows almost same result with what President Kim said during 1998. Figure 6 shows some important results of the simulation. Since early days of Korean financial crisis, President Kim expressed his opinion that Korean economy will be recovered within 18 month. Figure 6 shows that the foreign currency reserve in Korea is recovered at around 16th month. Similar to what President Kim said. Also, competitiveness of Korean companies has been recovered as he predicted . With these results, one can say that the cognitive map is sufficient to explain his policies. These results demonstrate that the simulation of cognitive map with the help of NUMBER can be useful.

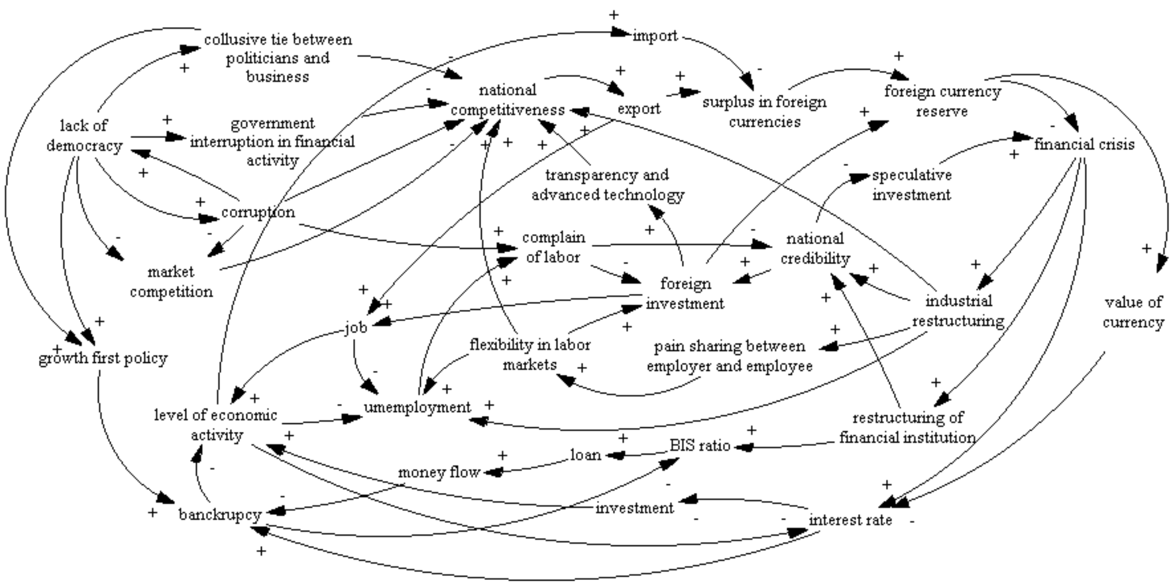

Figure 4. Cognitive map of President Kim Daejung in overcoming financial crisis

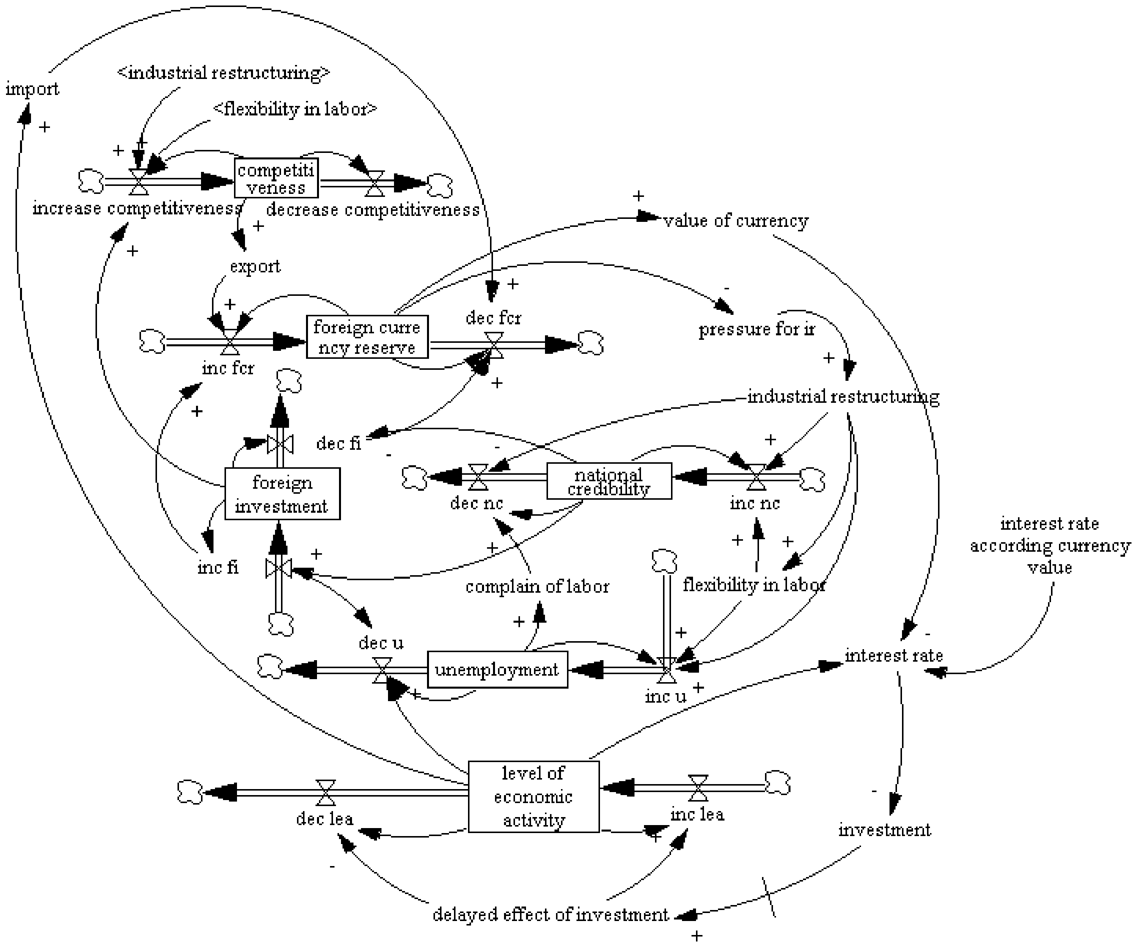

Figure 5. A system dynamics model derived by applying NUMBER to the cognitive map

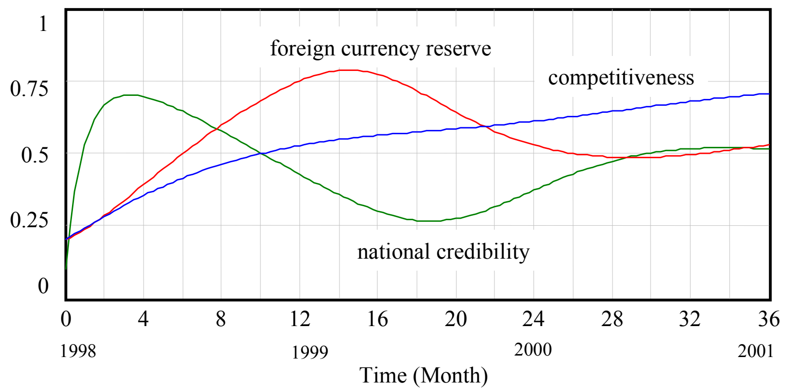

Figure 6. Results of simulating cognitive map

CONCLUSION

In this study, the author proposed that abstract simulation is necessary to get insights into the behavior of cognitive maps. The method of NUMBER was introduced and discussed as a way for performing abstract simulation. The author believes that there may be diverse methods for abstract simulation. The abstract simulation method and some technologies for doing it will extend the application area of system dynamics. Furthermore, the abstract simulation will help consultants in analyzing and simulating a cognitive map to overview the fundamental mechanism of decision makers' mind. Author hopes that abstract simulation and

NUBMER will be a bridge between insights from structures and impression from behavior of decision makers.

REFERENCES

Axelrod, R. (1976). *Structure of Decision: The Cognitive Maps of Political Elites*, Princeton University Press

Bonham, G.M., Shapiro, M.J. (1986). “Mapping Structures of Thought,” Gallhofer, I.N. et al (eds.), *Different Text Analysis Procedures for the Study of Decision Making*, pp.29-52, Amsterdam: Sociometric Research Foundation.

Coyle, R.G. (1998). “The Practice of system dynamics: milestones, lessons and ideas from 30 years experience," *System Dynamics Review*, Vol. 14, No. 4, pp.343-365.

Coyle, R.G. (1999). "Qualitative Modelling in System Dynamics or What are the wise limits of quantification?" *Proceedings of 1999 Conference of System Dynamics Society*, New Zealand.

Eden, C. (1988). "Cognitive Mapping," *European Journal of Operational Research*, Vol. 36, pp.1-13.

Eden, C. (1994). "Cognitive mapping and problem structuring for system dynamics model building," *System Dynamics Review*, Vol. 10, No. 2-3, pp.257-276.

Jenkins, M., G. Johnson (1997). "Entrepreneurial Intention and Outcomes: A Comparative Causal Mapping Study," *Journal of Management Studies*, 34:6, pp. 895-920.

Kardaras, D., B. Karakostas (1999). "The use of fuzzy cognitive maps to simulate the information systems strategic planning process," *Information and Software Technology*, Vol. 41, pp.197-210.

Kim, Daniel (1992). *Systems archetypes: Diagnosing Systemic Issues and Designing High-Leverage Interventions*, Pegasus Communications.

Kim D.H. (1999). "Systems Thinking in the Management of Korean Economic Crisis" *International Conference of System Dynamics Society*, Newzealand.

Meadows, D.H. (1982). "Whole Earth Models and Systems," *Coevolution Quarterly*, Summer, pp.98-108.

Richardson, George P. & A.L. Pugh (1981). *Introduction to System Dynamics Modeling with DYNAMO*, Cambridge, MA:The MIT Press.

Richmond, B. (1993). "Systems Thinking: Critical Thinking Skils for the 1990s and Beyond," *System Dynamics Review*, Vol. 9, pp.113-133.

Roberts N., D. Andersen, R. Deal, M. Garet, W. Shaffer (1983). *Introduction to Computer Simulation: A system Dynamics Modeling Approach*, Addison-Wesley Publishing Company.

Senge, P.M. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization*, New York: Doubleday.

Weick K.E., M.G. Bougon (1986). "Organizations as Cognitive Maps: Charting Ways to Success and Failure," Sims H.P., Gioia D.A., (eds.), *The Thinking Organization*, Jossey-Bass Publishers.

Wolstenholme, E.F. (1990). *System Enquiry: A System Dynamics Approach*, John Wiley & Sons.