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A Method for Direct Conversion of Causal Maps into SD Models: Abstract Simulation with NUMBER

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Abstract: *Causal maps and cognitive maps have been widely used to get insights into complex systems and minds of decision-makers. When insights come from the system behavior rather than its structure, there is a need to simulate causal maps and cognitive maps. In this paper, the concept of abstract simulation is proposed to allow simulation of causal and 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 several causal maps of system archetype and a cognitive map of policy maker to show its usefulness.*

I. 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.

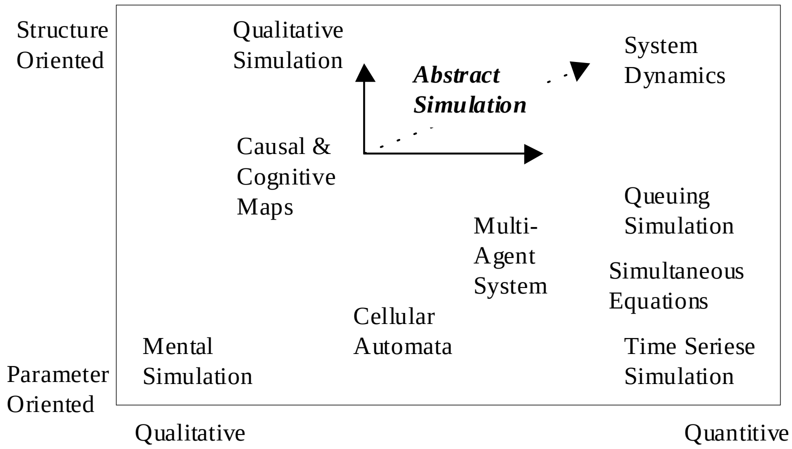


Figure 1. Diverse ways of simulation and Abstract Simulation

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.

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.

II. NUMBER for Abstract Simulation

In this study, a method for directly converting causal maps and 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 causal map into a SD model. First, several variables in the causal 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.

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

Safe formula	Meanings
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.

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. 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

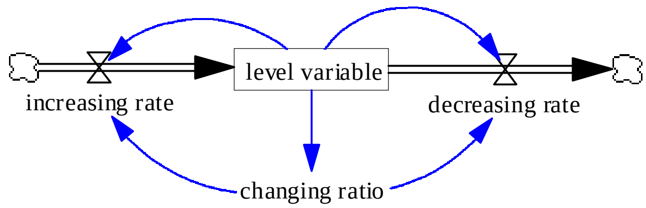


Figure 2. Elementary relationship between level and rate variables

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.

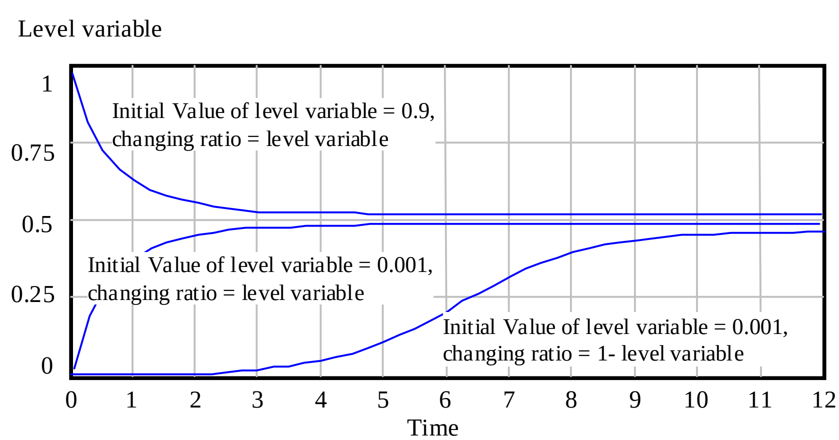


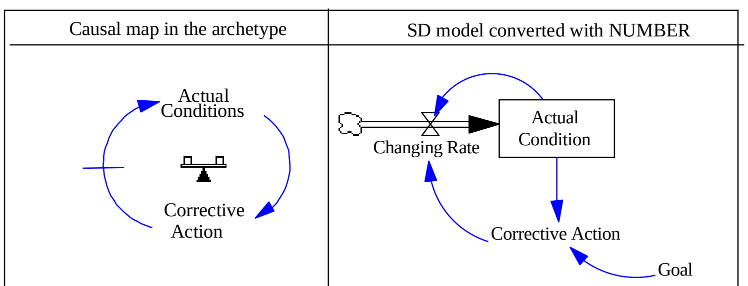
Figure 3. Time behavior of elementary relationship

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 several causal maps of systems archetype and cognitive map of policy maker.

III. Applying NUMBER to Causal Maps in System Archetype

Causal maps for system archetype are famous for their simple structure and rich insights. But they cannot show any behavioral implication and thus do not allow any behavioral experimentation (Lane & Smart 1996). Causal maps of system archetype are rich in structural implication but poor in behavioral insights. NUMBER can provide this missing link between structure and dynamic behavior. Figure 4 shows the results of applying NUMBER to the archetype of "balancing process with delay".



Equations

Actual Condition= INTEG (+Changing Rate, 0.5)
Changing Rate= (1-Actual Condition)*DELAY1(Corrective Action, 5)
Corrective Action=Goal-Actual Condition

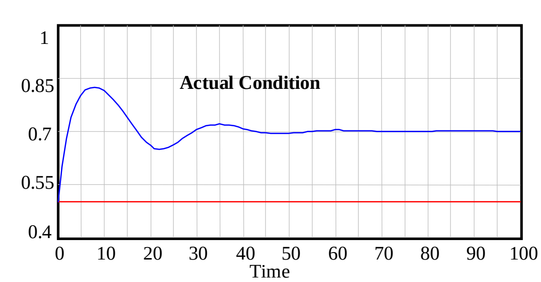


Figure 4. Applying NUMBER to the archetype of balancing process with delay

While applying NUMBER to this archetype, "actual condition" is treated as level variable. Delay function can be used in the equation as with normal SD modeling. One can see that the concept of goal is necessary to produce any meaningful behavior. The 'Goal' variable must be included in the archetype to generate fluctuating behavior. Figure 4 shows that the system dynamics model derived by applying NUMBER is simple enough to preserve the generic nature of the archetype.

Figure 5 is the result of applying NUMBER to the archetype of "fixes that fail". In this archetype "problem" is represented as level variable. The two rate variables for increasing and decreasing problem is introduced automatically. SD model in figure 5 demonstrates that 'fix' and 'unintended consequence' are related to the rate variables. While 'fix' affects the rate variable of decreasing problem, 'unintended consequence' changes the value of "increasing problem" with some time delay. Time behavior of problem shows that the problem will reappear after a short-term reduction in the problem.

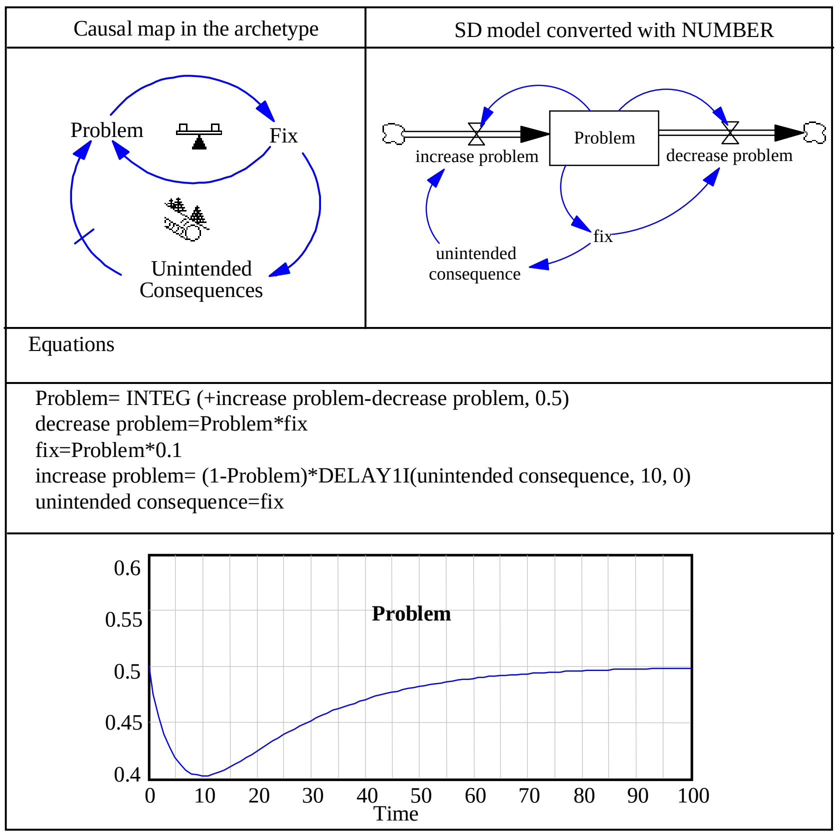


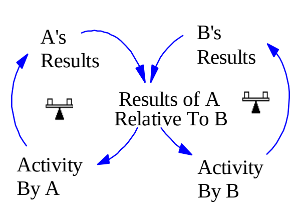
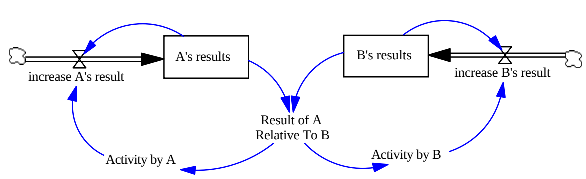
Figure 5. Applying NUMBER to the archetype of fixes that fail.

In the time behavior of the Problem, one can find that the reduction of problem by introducing fix takes place rapidly, while its reappearance takes long time. This asymmetry in the time behavior of fix can provide a biasing impression that fix is efficient and the reappearance of the Problem is a natural phenomenon rather than a result of the fix itself. In this example, system behavior reinforces wrong belief in casual effectiveness. With this kind of biasing impression, one may become addicted to the measure of symptomatic fixes at every time when the problem reappears. In this way, system behavior of the archetype can provide additional insights into the fundamental problem of the archetype afflicting decision-makers.

Figure 6 and figure 7 are results of converting archetype of escalation and success to the successful into SD models by using NUMBER. The stock and flow diagram of figure 6 and 7 are as simple as their corresponding causal maps. Only the rate variables are added to the original causal maps. Even though these SD models are simple, they can produce time behavior of the level variables. Time behavior in figure 6 and figure 7 show escalation effects and the effects of success to the successful mechanism.

In figure 6, results of A and B grow fast in the beginning, but their growing will stop near the limiting points of those variables. Also, figure 7 shows that resource for A will grow to his maximum, while resource of B will be depleted completely. These time behavior of the level variables cannot be elicited from the structures of causal maps alone, because there are no limiting factors in the causal maps. But, any variable cannot grow or decay infinitely. And thus the growing and decaying rates will be slowed down as they come to the extreme points. These time behavior comes form the assumption on the unit boundary discussed above.

By applying NUMBER to several system archetypes, one can find that causal maps can be converted into SD model without loosing their simplicity and thus their generic nature. At the same time one can simulate the simple and generic SD models derived from the causal maps. One can learn by observing system behavior as well as its structure. Furthermore, one can experiment various policy measures with the SD models. For example, in figure 7, one can introduce some program of supporting the weaker B, and one can simulate the model and get insights from the simulation results. In this way, one can use the system archetype as a learning environment that allow not only deep understanding but also risky experimentation and playing.

Causal map in the archetype	SD model converted with NUMBER
	

Equations

A's results= INTEG (increase A's result, 0.1)
Activity by A=IF THEN ELSE(Result of A Relative To B<0, 0.5, 0)
B's results= INTEG (increase B's result, 0.05)
Activity by B=IF THEN ELSE(Result of A Relative To B>0, 0.5, 0)
increase A's result= (1-A's results)*Activity by A*0.1
increase B's result= (1-B's results)*Activity by B*0.1
Result of A Relative To B=A's results-B's results

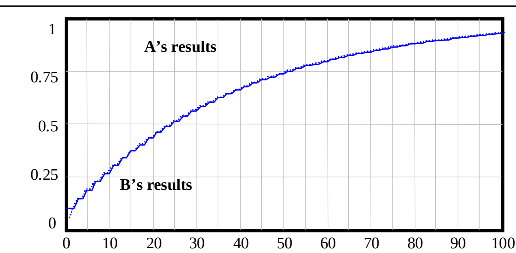
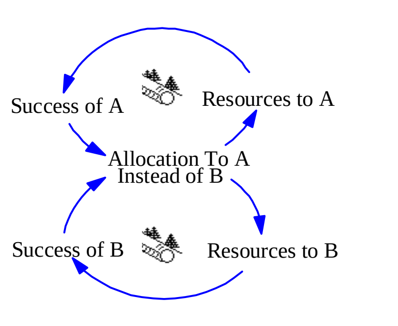
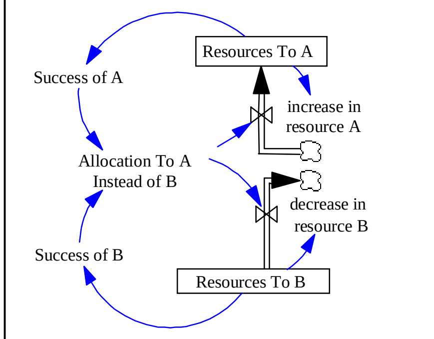


Figure 6. Applying NUMBER to the archetype of escalation

Causal map in the archetype	SD model converted with NUMBER
	

Equations

Resources To A= INTEG (increase in resource A, 0.5)
increase in resource A= (1-Resources To A)*Allocation To A Instead of B
Success of A=Resources To A,   Success of B=Resources To B
Resources To B= INTEG (-decrease in resource B, 0.45)
decrease in resource B=Resources To B*Allocation To A Instead of B
Allocation To A Instead of B=IF THEN ELSE(Success of A>Success of B, 0.05, -0.05)

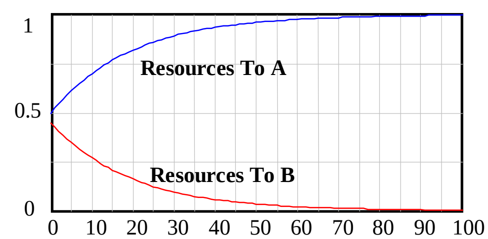


Figure 7. Applying NUMBER to the archetype of success to the successful

Another important thing that NUMBER can provide is the criteria for judging what archetype will match to real situations. Traditionally, system archetypes are applied to real situations on the basis of structural similarity between them. But, in order to select appropriate archetypes, one needs behavioral similarity as well as structural similarity. If there are structural similarity but no behavioral similarity, one must search other crucial structural mechanism to explain the behavioral gap. Furthermore behavioral similarity between archetypes and reality is important because most decision-makers are accustomed to understand their environments in behavioral terms. By applying NUMBER to causal maps, one can provide behavioral insights to every day decision-makers and can enhance their understanding in system archetype and its meaning in real life.

IV. Applying NUMBER to Cognitive Maps of Policy Maker

In the previous section, NUMBER was applied to simple causal maps. NUMBER can be applied to rather complex causal 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 8 is a cognitive map of President Kim Dae-Jung collected from his statements in 1998 (Kim 1999). And figure 9 is a system dynamics model derived by applying NUMBER to the cognitive map of figure 8. Only some important variables that form feedback loops in the cognitive map are included in the system dynamics model of figure 9.

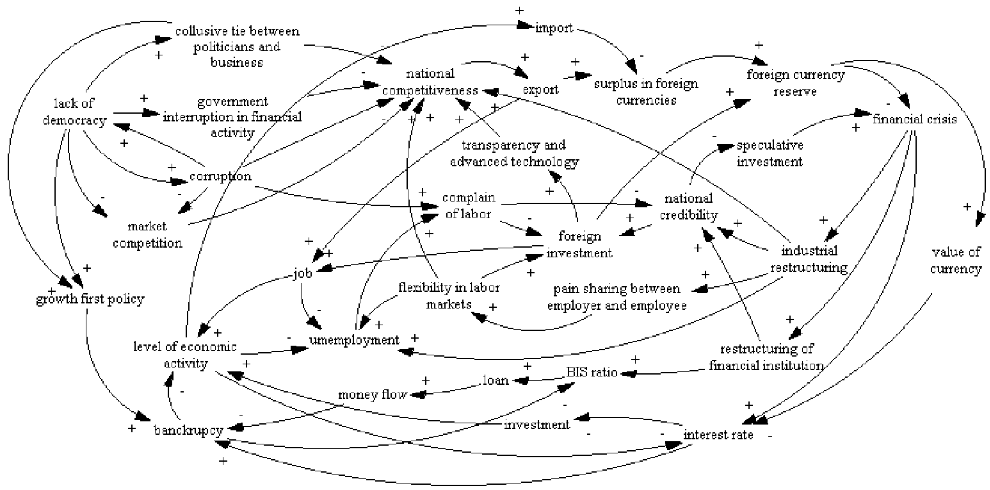


Figure 8. Cognitive map of President Kim Daejung in overcoming financial crisis

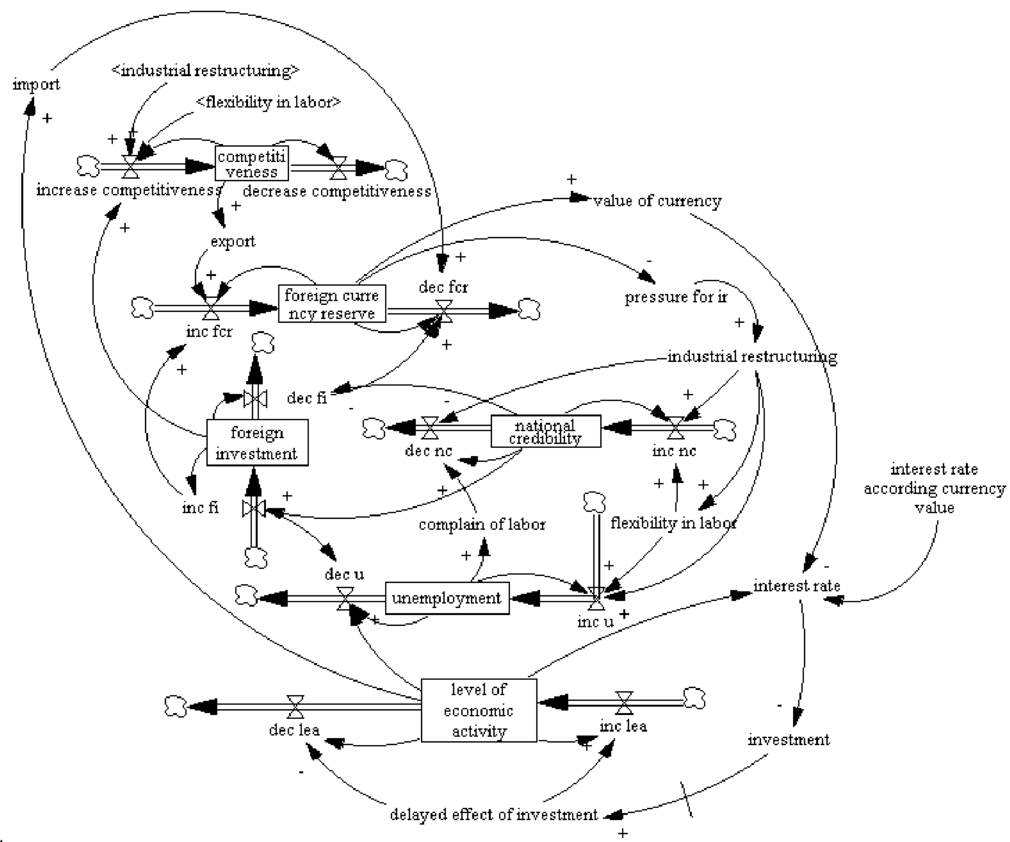


Figure 9. A system dynamics model derived by applying NUMBER to the cognitive map

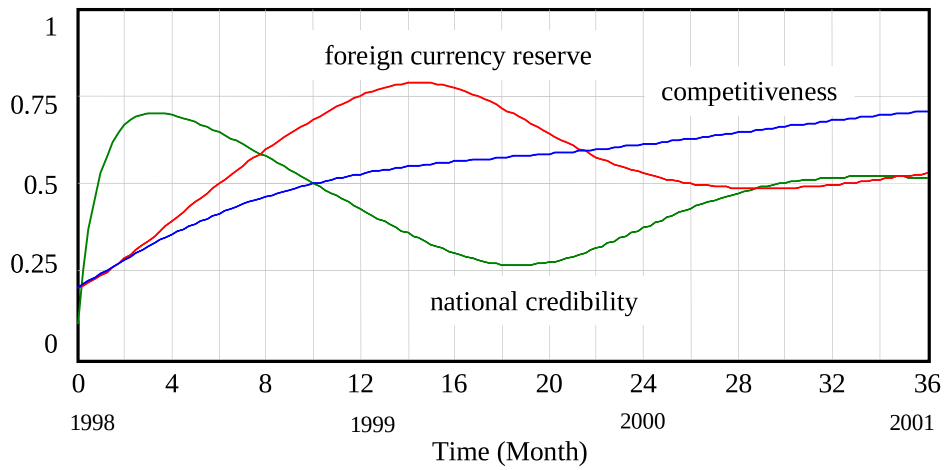


Figure 10. Results of simulating cognitive map

When the SD model of figure 9 was simulated, the author was surprised to find that the simulation shows almost same result with what President Kim said during 1998. Figure 10 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 10 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.

V. Concluding Remarks

In this study, the author proposed that abstract simulation is necessary to get insights into the behavior of causal maps and 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 building a quick causal map to overview the fundamental mechanism and will allow its simulation. As there are archetypes of system structures, there are archetypes of system behaviors. Linking pins between them will enhance our understanding the dynamics of complex systems. Author hopes that abstract simulation and NUBMER will be a bridge between insights from structures and impression from systems behavior.

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