THE COMPARATIVE STUDY ON SYSTEM DYNAMICS AND GREY SYSTEM THEORY

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ABSTRACT

System dynamics created by professor Jay W. Forrester at MIT, is a field which bases on system theory, absorbs the quintessence of control theory, and draws support from computer simulation technique. Established by professor Deng Julong at Central China Institute of Science and Technology in 1982, grey system theory derives its idea and methodology mainly from control theory and operations research. Although system dynamics and grey system theory both have their own features in methodology and processing technique, there are still a lot of common points between them. From the comparative study on these two fields, the paper arrives at that it is not only necessary but also possible to infiltrate and draw on the experiences of each other to develop themselves.

The new system analysis, modeling and decision-making approaches have being developed with the development of science and technology. System dynamics and grey system theory are two of such new fields.

1. THE GENERAL DESCRIBTION OF SYSTEM DYNAMICS AND GREY SYSTEM THEORY

System dynamics is a new field built by professor Jay W. Forrester at MIT. Based on the deep study on economy and industrial organizations (the system including people, finance and technology), Forrester pointed out a lot of points of view about the information feedback system and the basic system components. The new cross field was founded based on system theory, absorbed the quintessence of control theory and information theory, and got help from computer simulation.

Grey system theory is the new theory founded by professor Deng Julong at the Central China Institute of Science and Technology in 1982. Professor Deng pointed out and developed the new concepts of grey system based on the deep inspection of the special system problems in which the known and unknown information are both contained in the system, and created the new theory which extends to the social economic system and combines

automatic control science and the mathematics methods of operations research.

System dynamics has developed its own theoretic system after 30 years development. Grey system theory is also formed the theoretic system with its own characteristics although it is only several year history. It can be seen that there are many aspects in thinking methods and processing ways where one theory is similar to, complement of and draws on the experiences on the other after the comparative study on the theoretic system of system dynamics and grey system theory. It is hopeful that such comparative study can push them to develop further.

2. THE ANALYSIS METHOD COMPARISON BETWEEN SYSTEM DYNAMICS AND GREY SYSTEM THEORY

1) The concept of system

System dynamics and grey system theory define that a system is the sum of its parts that operate together for a common purpose.

Based on the definition above, " grey system " means the system in which both known and unknown information are contained. It should be pointed out that the human actions can be composed of in the systems of interest.

2) The idea of system analysis

System analysis is the most important tool to make the system structure be clear and to give the possibility for the system simulation and computer modeling.

There is a lot of unknown information in the real world. The idea of analysis is to get the unknown information as more as possible, and to make the unknown system be clear. The " black box ", " grey box " methods and grey system theory are all system analysis methods developed when analyzing system. " Black box " method means that system analysis is made by the way that from the outside of the system, from the direct causal relationship, and from the input-output relationship when the inner structure, characteristics, and parameters of the system are all unknown and impossible to analyze the inner structure.

It is true that there are some systems in the real world such as the brain system of human being which are difficult to be analyzed from the inner structure currently. "Black box" method is a possible way to study them. But for social economic and engineering systems, it is possible to analyses inner structure directly. There are many advantages to analyze the system from the inner structure, because the behavior of the system can be easily grasped at higher degree of confidence by the way. From the inner structure to analyze the system is the method which is applied by system dynamics. From the micro-structure of system,

system dynamics analyzes and grasps the characteristics and the behavior of system based on the inner sructure, parameters, and the general function of system.

"Grey box " means some of structures, parameters, and characteristics of a system are known and the other unknown. Professor Deng Jiulong supposes the box has the special meaning of decoupling the inside from the outside, but for the " grey box " the known parts in it should be used effectively, therefore he created the new concept of grey system. It is not only to study the causal and input-output relation of the system from the outside behaviors, but also to study the inner structure, parameters, and behaviors of system from the inside by grey system theory. The later is more concerned for playing the role of " white information " as best as possible.

From the comparative study on the ideas of system analysis of these two fields, it can be obviously found that system dynamics and grey system theory both pay attention to studying the inner structure of system and to using the "white information " from the inside of system effectively. From the recognition process, the system dynamics and grey system theory have the same process gradually from unknown to a little bit understanding, then to more understanding.

From the comparative study on the modeling of these two fields, it can be found from the appearance of model that the model based on grey system theory contains grey parameters, but the model based on system dynamics does not. We should consider the later model as the result of whiting system. To white the system is realized by the continuously researching on the boundary, structure, and parameters of systems and applying some other ways (including the experiences and judgements of human being) to estimate the parameters of system. The precision of whiting process is not so perfect, because on one hand there is different prejudice of human being in the whiting process, on the other hand it is impossible to understand the inner structure and parameters of system precisely even there is no any prejudice of human being according to Heisenberg's principles of inprecise measurement and Gödel's theorem of unperfect ability.

3) The method of system analysis

Grey system theory is the product of lengthening the points of view and methods of control theory to social economic system, so the methods of system analysis of grey system theory continue to use a series of analysis method of control theory. Such methods include controllability, observability, stability analysis and dynamic characteristic analysis of system.

The controllability of system mainly concerns the changable property of the input to the state of system. It is meaningful to the social economic system. Since the input of social economic system include some policies. It is the worst if the input policy

can not control the social economic system. Based on the method of control theory, grey system theory studies the controllability of grey system and gets some meaningful conclusion. System dynamics also studies the controllability if necessary, and has got success in some cases.

The observability of system mainly concerns the observable property of system state directly from the system output. For general systems, it is not easy to measure the system state directly, it can only be measured from the output of system, so it is significant to study the observability of system. For the system of system dynamics involved, the study of observability of system is not so important as grey system theory. The level variables in system dynamics models stand for the system state and have real meaning. Some system states are measurable, some are not, the observation of system states can be realized by printing all level variables in system dynamics models when simulation. When some system state variables are unmeasurable, it is necessary to study the observability when system states should be measured and the observation of system states can be realized by Kalman filtering and other methods. The study of observability for grey system is significant. Because it can answer whether the system state can be observed from the output when there are some grey elements in the structure. If the grey system is observable, it means the observability of system state does not change with the change of grey elements.

The stability of system is one of the most important properties. The higher stability, the higher ability of disturbance resistance and vice versa. The problems grey system involved are mostly linear problems. The scale of the problems are not very large. The analysis methods are mainly time domain analysis. The stability of grey system can be researched from the eigenvalue analysis. The problems system dynamics involved are generally large scale, nonlinear, so the concept of stability analysis is more complex than that of grey system theory. System dynamics applies time domain and frequency domain (the combinative study on the properties of amplifier-frequence and period-frequence) methods to analyze the stability of the linar system and the system which can be linearized. System dynamics also apply the frequency domain method to analyses the stability for the system which can not be linearized or the stability can not be judged after the linearization. Lyapunov first method is often applied in system dynamics. Lyapunov second method can be also applied in system dynamics for the problems of Lyapunov function which can be searched by Krasovskii method.

The dynamic characteristic analysis concerns the sensitivety of the change of inner structure to the change of system behavior. Grey system theory applies some methods derived from linear control theory such as eigenvalue analysis to linear problems. But eigenvalue analysis method is not the only one method in system dynamics since the problems system dynamics handled are large scale and nonlinear. Therefore the new methods with system

dynamics character have developed--the dominant loop analysis and sensitive parameters analysis. System dynamics considers that the basic unit of system structure is feedback loop, and the behavior of system is determined by the structure. Furthermore there are some dominant loops in the structure which almost determine the behavior of system. The dynamic behavior can be discoverd by the way of searching and analyzing the dominant loops. The special software DYNASTAT has been developed to analyze the dominant loops in system dynamics. DYNASTAT can be conveniently applied to search the dominant loops in nonlinear and large scale systems to research the dynamic property of system. The dominant loop analysis method in system dynamics is contributed to large scale system theory. The idea of dominant loop analysis has general meaning to large scale system.

After comparison of system analysis methods of the two fields, it is obvious that based on nonlinear large scale system system dynamics enlarges a series of analysis methods which originated from modern control theory and creats some new methods with its own feature. But grey system theory continues to use the analysis method of modern control theory.

3. THE MODELING METHOD OF SYSTEM DYNAMICS AND GREY SYSTEM THEORY

System modeling is the preparatory step of decision-making. A model which describes the basic structure of system provides the fundamental for system simulation and decision-making.

The following points can be seen after the comparison of the two fields.

1) The models of system dynamics and grey system theory are both differential equations. The process of modeling in system dynamics and grey system theory are similar to. The sequence of the process is a) mental model, b) network model, c) quantitative model, d) dynamic model, e) optimal model.

2) System dynamics considers nonlinear and large scale property. So the system dynamics model can reflect nonlinear and large scale property of system. Grey system theory is not so strong in dealing with nonlinear problems (at least currently). As there is distance between linear large scale system theory and practical application, grey system theory can only solve middle or small scale systems successfully now. With the development of grey system theory and large scale system theory, it may be used to solve large scale problems in the near future.

3) Based on the overall analysis of system, system dynamics pays attention to the fundamental components of system--information feedback loop structure. System dynamics model is not only a function simulation but also a structure simulation because system dynamics pays attention to the function and structure of systems simultaneously when modeling. System dynamics model is

the structure--function model. System modeling way--from micro structure to build fundamental structure and furthermore to simulate and analyze the property, is different from the common modeling way (black box method) and suitable to understand the complex system problem. Although grey system theory overcome the limitation of " grey box " and pays attention to the information usage from the inner structure of system, it does not overcome the limitation of function simulation way (black box). Grey system theory models only reflect the function of system, it does not consider the structure of system.

4) System dynamics pays attention to the judgement of human being in modeling. Some of the parameters in model are estimated by the experience of human being. System dynamics assumes that the system behavior is mainly determined by inner structure and parameter, and the structure is the most important factor to determine the system behavior. System dynamics does not pay the same attention to the estimation of all parameters. Some key parameters (sensitive parameters) should be searched before estimation of all parameters and should be estimated accurately. The other parameters (nonsensitive parameters) can be estimated roughly. System dynamics not only applies some common parameter estimation methods such as Least Squares method, but also develops some special parameter estimation methods such as Full Information Maximum Likelihood Estimation .

Grey system theory pays more attention to accuracy data process technique to determine the parameter of system. But it seems that grey system theory does not pay enough attention to the experience and judgement of human being. System dynamics and grey system theory can draw on the experience of each other on the two points above.

4. THE SIMULATION AND FORECAST IN SYSTEM DYNAMICS AND GREY SYSTEM THEORY

System simulation can give different solution in different conditions (system parameter, environment change and input change). The decision maker can select the optimal or quasi-optimal solution among them.

In fact, system solution can be found by the analytic method without simulation for simple linear systems. The optimal solution can be convinently found by such method. The special software should be developed to deal with the complex computing problems to reduce labor tension. This is the idea of grey system theory.

It is very difficult and even impossible to find analytic solution for nonlinear or complex linear problems by analytic method directly. As there are some difficult in computation, the special software is not easy to develop.

It is grateful that grey system theory developed and applied the effective data process technique in forecast. Some satisfied results have been reached in use of residual information and the higher accurat results in the short term forecast have also been reached in use of residual identification information.

Compared with grey system theory, system dynamics pays much more attention to simulation technique. The special simulation language DYNAMO has been developed and all nonlinear system problems can be solved by it. As high speed computation of computer and the DYNAMO ability of dealing with nonlinearity and time delay, it is convenient and fast to apply DYNAMO to simulate the different results of nonlinear, time delay, and large scale problems in different conditions (structure parameter, environment and input-output change). Another advantage DYNAMO has is that the model built by DYNAMO corresponds to the structure of problems (variable, structure corresponding). The simulation solution of system dynamics may be data output or curve output. Based on DYNAMO, the imagination of decision maker and system parameter change, environment change can be easily and fast simulated on computer. So decision can be easily made after the comparison of the output.

It is very difficult and even impossible to find the optimal solution to nonlinear large scale syetem (especially to social economic system). But as DYNAMO has the convenient and fast simulation ability, it is possible to simulate some different typical conditions. So some quasi-optimal solutions can be found among the simulation results corresponding to a series of different policies, environment and condition change if such changes and policies can be considered carefully by policy designer. Such solutions are not optimal, but many conditions including system environment and other changes have been considered when simulation, so they are the " optimal solution " we can find currently. Therefore we can consider system dynamics as a powerful tool that can be used in laboratory to design and analyze policy by decision maker. To some extent system dynamics has promoted a revolution in research methods of social science.

The meaning of forecast in system dynamics is discussed under given conditions. System dynamics pays attention to the structure research and builds model from the micro structure. Compared with grey system theory, system dynamics has the function of long term forecast. System dynamics and grey system theory have the similar accuracy in short term forecast. In fact, it is not consistent between the experience and judgement of human being and usage of residual information, the long term forecast with lower accuracy corressponding to short term forecast with higher accuracy. It seems impossible to solve the contradiction above in methodology.

5. DECISION-MAKING IN SYSTEM DYNAMICS AND GREY SYSTEM THEORY

H. A. Simon considers that the decision-making of human being is

partly rational, scientific and logic. That means decision maker can only make decision based on the limited information souce through the process of science and logics. Decision-making in system dynamics and grey system theory can only be partly rational, scientic and logic.

Except few simple systems, system dynamics considers that the most decision-making process have been involved by human being. As the careers and prejudice are different for different people, it seems impossible to make optimal decision by decision maker. System dynamics pays attention to the effect of human being when decision-making and does not seek the optimal solution without the effect of human being. The experiences and judgements of decision makers have been used to conceptuate and analyze the possible conditions in system dynamics, then the different policies can be studied. In such a way, some selectable decisions can be given to actural decision maker to make the last decision based on their own experiences and judgements.

The decision theory of grey system theory is mainly come from operations research. The view of point of optimization has been stressed in grey system theory. Grey system theory developed the linear program and nonlinear program in operation research to grey linear program and grey nonlinear program, developed regional planning theory to grey regional planning, and developed game theory to grey situation decision-making.

It is expectful that a new effective theory and method which based on system dynamics absorb advantages from other system fields to form system thinking, simulation and search for optimal in dealing with nonlinear and complex system problems will be developed in the near future.

From the preliminary comparative study between system dynamics and grey system theory in the paper, it can be found that there are many similar aspects in methodology and process techniques between system dynamics and grey gystem theory. Some of them are exact same, some of them are not, and some of them have large difference. The tendency of infiltration and cross in the development process of science and technology has been becoming stronger and stronger. It is hopeful that the probability of drawing on experience from all fields for each one will be greater and greater with time.

REFERENCES

Forrester, Jay W., 1968. Principles of Systems. Mass.: The MIT Press
Wang, Qifan., 1984. System Dynamics. Printed at Shanghai Institute of Mechanical Engineering

Forrester, Jay W., 1980. Industrial Dynamics. Mass.: The MIT Press
Deng, Julong., 1985. Grey System: In Society and Economy. The National Defence Industry Press
Deng, Julong., 1985. Grey Contral System. The Central China University of Science and Technology Press
Simon, H. A., 1985. The New Science of Management Decision. (Translated into Chinese) The Chinese Social Science Press
Wang, Qifan., Philosophical Views and Basic Theories of System Dynamics. Proceedings of the 1986 China National System Dynamics Conference.
Wang, Qifan., On the Statistical and Estimative Problems of the Parameters of System Dynamics Model. Proceedings of the 1986 China National System Dynamics Conference.