PHILOSOPHICAL VIEWS AND BASIC THEORIES OF SYSTEM DYNAMICS *

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ABSTRACT

System dynamics, founded by professor Forrester at Massachusetts Iustitute of Technology in 1956, is a discipline which analyzes and studies the system of information feedback. Basic views of theories of system dynamics distinctively show its dialectical characteristics. More attention should be paid to the features of complicated nonlinear systems. The model simulation of system dynamics is a kind of structure-function simulation. One of the remarkable advantages of system dynamics is that it can handle problems of high order, nonlinear, and multiple-feedback system.

PREFACE

System dynamics, which was founded by Jay W. Forrester at the Massachusetts Institute of Technology, is a field which analyzes and studies information feedback systems.

Since the late 1950s, system dynamics has been gradually becoming a new field. It was first applied to the management study of industries and enterprises, such as the fluctuation of employees and production, and instability of the stock market and market growth. Since then, its application has been enlarged, from the civil use to military use; from the scientific research and the management of designing work to the decision of a city's getting rid of economic stagnation and recession; from the menace of exponential growth of world population to the crisis of consuming all non-renewable resource resource; to studying the pathological hypotheses for examining diabetes to crimes. In all, system dynamics has been applied almost to all fields of systems and its application continues to be stretched. In the decades since 1970, Forrester has finished a system dynamics national model of the U.S. The model has been used to study social and economic problems of America as a whole. Many long-time-exsited problems, which have long puzzled economists such as economic long wave, have now been solved. Due to the research achievements from the national model and the theory of long wave, system dynamics, this newly-established field, has achieved great development in its theory and application research, and it has become highly advanced.

Several years ago, the theorectical and applied research on

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system dynamics started in China. The first academic conference of system dynamics in China was held in August of 1986. In response to an upsurging enthusiasm in studying theories of system science in China and other countries this paper sheds light on the philosophical views and basic theories of system dynamics.

THE DIALECTICS IS THE CORE OF THE SYSTEM DYNAMICS THEORY

Basic views of system dynamics theories outstandingly embody its dialectical characteristics. It emphasises a system view, and related and development views, it puts emphasis on the principal contradiction and the main aspect of a contradiction; knowability of things; that practice is the unique criterion of the truth.

System views of system dynamics.

Thirty years ago, system dynamics came into being with its sharp system views. The system is objective, universal and it exists everywhere. All things are part of a system. Both the boundless universe and the micro-world,without exception, are made up of systems. A system contains subsystems, some related and conditioned systems can make up of a much larger system. Industry dynamics, appearing at the initial stage of system dynamics, sharply and distinctively reveals disadvangtages of that time. For example, it reveals the problems of the processing industry. Finance, distribution, organization work, advertisements were separated and taken as disjointed; they were not taken as parts of an integrated system. Only up to 1960s, industry dynamics was widely applied to all kinds of fields, and its theory system became perfect and a general discipline which studies all kinds of systems. By this way, system dynamics came into being.

Dialectical connection and development views

It has been considered by system dynamics that between entirety and parts of a system, parts and parts, a system and environment there exsit relations, formed because of information feedback, which interact and condition one another and control one another. Any system only can exist and develop by being present among relations. The relation of information feedback and changes, motions and developments, which exsit inside and outside of a system, are closely related. By examining from the inside of a system, the internal relation is the basis and motive force of a system; while the external ones are the objective conditions for its motion and development. In addition, the motion of a system is a process of development from a low form to a high form, between these two forms, there is a historical relation of the present and the past. No doubt, this kind of connection and development view is the principal characteristic of dialectics.

Principal contradition and principal aspect of a contradition

The principal contradiction and the principal aspect of a contradition strongly emphasizes the main variables and loops made up of these variables in applying system dynamics to analyze and settle system problems. It is just the characteristics of these principal loops and the effects between them that principally determine characteristics and behavior modes of a system. This is a principle of the leading part effect. And under certain conditions, the principal and nonprincipal parts may change their positions. All this we have discussed here are the principal contradition and principal aspect of a contradition which are studied by dialectics in handling problems of the particularity of a contradiction.

Objective matters and knowability of the world.

The scholars of system dynamics think that the objective world is of knowability. Just when the western industries and enterprises were confronted with the production and employees fluctuation, with the instability of the stock market and market growth; with the stagnation of the city development and recession; all of which made people at a loss of what to do, system dynamics faced this challenge bravely. System dynamics thinks that all these influences and actions come from the internal structure of a society and economics. It is just on the basis of knowability of the objective world, the scholars of system dynamics have taken the theories of system dynamics as the arms of exploring the secrets of a system. On the basis of qualitative analysis, a mathematical model is built against system problems. And the system is analyzed quantitatively. This is a process of knowing and solving a problem, which is a process of from the inside to the outside and from the low level to high level. The model of system dynamics is a "laboratory" of the objective system. With the help of the model simulation, a model can be dissected (analyzed), and more affluent and profound information can be obtained. Furthermore, the relation between the internal structures of a system and its function is to be revealed, and the ways and channels to solve system problems may be found.

Practice is the criterion of the truth

System dynamics uses a mathematical model to describe the objective world and its internal structure, relation and law of a system. The model is not a duplication of a real system, it is only a representation or a simplified description of a system. There is neither a fairly perfect nor an ultimate model. So any models are only similar to a system under certain conditions. Without doubt, the reality and effectiveness of a model have to be tested and validated. System dynamics has a set of ways and procedures of testing a model including some statistical tests. The core of all the ways and precedures is to emphasize using objective facts (including historical facts) to test a model. To emphasize the application of a model reliability and validity are tested in application and practice. System dynamics considers that most of the traditional statistical ways are not adaptable for testing a model of system dynamics.

It is only practice and experience that are the most authoritative and ultimate criterion of testing a model and its simulation results.

BASIC VIEWS OF A SYSTEM OF SYSTEM DYNAMICS

The definition of a system

System dynamics defines a system as the following: An integrated entity which is made up of many different and interacting parts for a common function. System dynamics holds true that a system is made up of units, and their motion and information. Units are the basis of an existing system, where as information plays a crucial role in a system. On the basis of information, units form a system. And only by this way motion of units can form a integrated action and function. That is to say, a system is a integrated entity of its structure and function. The units of a system for system dynamics may include a system of the natural world, social systems and thinking systems; they are natural or artificial, social or engineering, economic or political, and psychological, medical or ecological.

System dynamics states that the system of the objective world is an open system, while under certain temporal and spatial conditions,some systems can be simplified into closed ones.

Basic structure of a system

The views about the basic structure of a system is an important part of the theory of system dynamics. It is well known that Wiener discovered some co-regularities by studying the internal regulating function of organisms and automatic control functions of the machinery system, and by introducing the concept of information feedback of the organic system to the machinery system. Cybernetics was founded. At the same time, Forrester first applied the concept of information feedback to the socio-economic system by inspecting dynamic problems of socio-economic systems, biological and ecological systems. When the industrial society was born, human beings were immersed by a sea of countless fragamented knowledge and experiences. This was due to the problem that there was no general structure which can wholly describe all kinds of systems and influences. The so-called structure is the order of units. It includes two meanings, first, it means each unit of a system, secondly, it means the interactions and relations of units.

In order to study the system, correct theories and principles are needed to describe and reveal the inner structure of the system, and further to efficiently analyze, explain and process the phenomena and data which are obtained through observation. Without an integreted structure, what is obtained in observation can be nothing but a mixture of fragmentary materials or a pile of many incidents. System dynamics believes that a feedback mechanism can be the basic structure which describes socio-economic systems and various other systems.

In system dynamics, the basic unit of a system is the feedback loop which integrates state, rate or, say, action and information of a system. They correspond to the three constituents of the system, i.e. unit, motion and information. The change of state variable is determined by the result of decision or action. And decision stems out of two souces: One is to rely on the self regulation of information feedback, which is a phenomenon universally existing in biological world, society and machinery systems; the others rely on certain special laws of the system itself, but not on the information feedback in certain conditions. The latter phenomenon exists in non-biological world. At such occasions, it's not that the information is not in existence, but that it's in an unutilized "potential" state. In terms of system dynamics flow diagram, it is equivalent to having the linking line between information and decision cut off. So, a feedback loop is basic structure consisting of three fundamental constituents which has been stated above: state, decision and information. A loop can be classified into two kinds: positive and negative. And a complex system consists of these feedback loops which are in interaction; their overlaping and interaction form the total function of the system.

Structure and function of a system

All systems have structure and function, to be exact, systems are unities of structure and function. The so-called function refers to the order of unit activities, or it refers to the movement of the unit itself or the total effect resulting from interactions among units. Using simulation technology, structure-function simulation being its striking feature, system dynamics can study and analyze qualitively and quantitatively. It deserts the common function simulation (i.e. black box simulation) method of the past. It, starting from micro structure, constructs the basic structure of the system, and further simulates and analyses the dynamic behavior of the system. Such simulation is more suitable for research on the problem that a complex system varies over time.

The structure of a system represents the constructing characteristics of it, while the function represents the behavioral characteristics. Contradiction of structure and function is relative. Function and structure determine each other. Under certain conditions, structure can transform to function, function can also transform to structure, these two are inalienable. Therefore, when we study a system, not only the function and behavior of the system should be considered, but also its structure. Through cross examining the function and structure of the system, a model, which can better reflect the real system both functionally and structurally, is to be established.

The relevant system must be carefully analyzed both structurally and functionally, in order to construct a system dynamics model which is of high effeciency and can meet the predetermined requirement. The relations of the various constituents of the real world should be deeply observed, and the behavior mode and its inner structure of feedback be related. Through analyzing, comparing, and distinguishing the above factors, a correct understanding of the system is to be obtained. This understanding should be further reflected in the structure of the model. Thus, modeling is just the process of analyzing the relation of the structure and function of the system, which is unity of opposites.

Consequently, system dynamics provides us a scientific method of studying the relation between system structure and function, with the principle that constructing a system model starts from micro structure.

The inner micro structure of the system and its macro behavior

The nature of system behavior is principally determined by the internal structure of the system, that is, the mechanism of the internal feedback structure of the system. Internal structure of the system has two meanings: one refers to the nature of its constituents and the nature of their relations, the more important one is the internal feedback loops and structures of the system and the nature of their relations. Although the behavior of a system is rich and colorful and a closed system may change greatly due to the external disturbances, the system's behavior and development all are rooted in the interior of the system.

System dynamics emphasizes the dialectical relation between the internal and external causes. Internal cause is the basis for the system to exist, change, and develop; external cause is the objective condition for system. The up and down of the exterior plays an important role under certain conditions. But finally, external cause can not function without the internal cause of the system.

Leading part and non-leading part

In the various feedback loops in the system, there exists one or more than one leeding loop. It's just the nature and the interaction between these leading loops that determine chiefly the nature of system behavior, which is just the principle of the leading part. Due to this characteristic, main factors can be made prominent to simplify the model of a system in certain temporal and spatial conditions. Leading parts exist not only in the steady system but also in development, movement and change of the system, also in its transition process from original steady state to new steady state. What should be pointed out is, emphasizing the leading part principle is not deserting the function of other parts in the system. The leading part can only form and exist in the interactions of other parts. System behavior is determined not only by the main part, but the result of all part's joint functioning. Besides these, leading part and nonleading part can transit to each other.

Diachronic system and evolution law of system

The internal structure, function and parameters change as time proceeds. From the beginning to the end of the whole process of system movement, its main loop is not unchanging, its position may be taken by others possibly due to the effect of the internal feedback structure of the system, as a result the leading loop and the non-leading loop transiting to each other. Units of a system and their relations are not unchanging, once the original structure and system collapses, the new structure and system come into being. This is a process of quantity change to nature change, also a process of developing from rudimentary system to high-level system. Dynamic system is the general form of a system, static system is only the special form, this is the embodiment of the diachronic feature and evolution law of a system.

THE VIEWPOINT OF SYSTEM DYNAMICS ON THE CHARACTERISTICS OF SYSTEMS

The general characteristics of a system

(1) A system has the important characterstics of wholeness and relativity.

The whole system does not simply equate to the sum of its parts. Although most systems are greater than the sum of parts generally, a whole system which is out of good organization is possibly smaller than the sum of parts. Without various parts, the discussion of total is meaningless. Viewing the whole system simply as the sum of various part, it's unavoidable to slip into metaphysics. The nature of a system is different from that of the units, the structure-function of a whole system is different from that of parts. The nature of the whole system is defined by its various internal units, it is almost always different from the nature of various constituent units; meanwhile, system structure also gives new characteristics to the various units. For instance, a system of a country consists of its population, production, finance and trade, transportation, resources and the energy resources etc. subordinate systems. It's obvious that the system of the whole country, its nature, structure and function, is not the simple algebraic sum of these subordinate systems. Only by mastering this can the principle of decomposition and composition be correctly applied when analyzing systems and constructing models to deal properly with the relations between the whole system and its constituent parts, as well as the relations between the whole model and various blocks, and further to put correctly the sub-structures into the larger system. The wholeness of the system comes from the nature of relation between various units. It's just these relations and through the information feedback function that leads to the formation of the structure and function of the system. Here, it embodies the relativity of the system. Relativity refers to universal relations of wholeness and parts, part and part, system and environment (open system), as well as the relation between units, energy (motion) and information. When we study objects as a system, we should firstly start from wholeness, also from the relation between system and units, unit and unit as well as system and environment, to reveal and study the nature and movement laws of the internal feedback mechanism of the system, further to master the structure and nature of the wholeness through the understanding of relations among parts.

In a complex system, there exists phenomena that one cause leads to multiple results, one result derived from multiple causes, even of crossing cause and effect chains. Thus, as the research enlarges and deepens, the original unidirectional cause and effect relations appear to be unreasonable. There needs to be a kind of cause and effect relation which should be more reasonable and can describe the mono-direction cause and effect relation of the past with the application of a feedback cause and effect relation. This is definitely a progress and deepening of man's recognition of system relativity.

(2) Levels and hierarchy of system.

System dynamics emphasizes that the units and the total structure of system exist in the relation of mutual relating, dependency and affecting; while various units, substructure and total structure have their relative independence. Consequently, levels and hierarchy of structure result. Moreover, due to the relative independency of process function, levels and hierarchy of function result. Then, since system is the unity of structure and function, the levels and hierarchy of structure and function dialectically unitedly form the levels and hierarchy of the system, that is, in all kinds of system in the objective world, there exists different levels and hierarchy. What should be noted is that systems of different levels have different laws. Although the laws of higher level system contain that of lower level system, they cannot be completely based on the laws of lower level system. What's more, lower level systems have the tendency of transiting to higher level systems, meanwhile various different system levels transit among themselves. In the course of inorganic world evolation, higher level system are formed by way of combination of various lower level systems, while in the organic world completely different laws govern the development of a system, that is, a higher level system stems out of a lower level system.

(3) Stability of system

The stability of a system is an important characteristic of systems. The so-called stability refers to the constancy and reliability of a system in the condition of being disturbed (i.e. raising and dropping). Systems can be classified into three types: stable ones, asymptotically stable and unstable. Which type does a system belong to exactly, is all based on the nature of the internal feedback mechanism of the system, in other words, the nature of unity of opposites between structure and function of the system. Some systems, under disturbance from inside and outside, with their special internal feedback mechanism being stimulated, have the ability of changing from a stable state to an unstable state, continually transiting to new stable state; this is another characteristic of system-adaptability, which is embodied in the stability of systems. Understanding the stability and reliability of this kind of system is helpful to analyze and study the relations between their behaviors and their internal feedback mechanisms, i.e. the mutual depending, mutual affecting relations between structure and function of the system.

(4) Purpose-fuleness of system.

The behaviors of certain systems have certain tendencies and purpose. These systems can gradually transit from one stable state to a new stable state, or approach new stable states through oscillation. For instance, a negative feedback system has the characteristic of seeking a goal, the purpose of this kind of system is determined by the internal feedback structural mechanism of the system, to be specific, by the relation between the internal various parts of the system and its total nature.

(5) Isomorphism of system.

In the different fields such as the natural world, human society and human thought etc. there exists the similarity characteristic in terms of structure and function, i.e. the isomorphism of system. This tells us that things and phenomena which seemingly belong to absolutely different field can be described with the same kind of law and behavior mode. For instance, the S shape increasing law can apply to describing certain things and phenomena in certain conditions and boundary, such as population growth, infection of disease, spreading of rumour, growth of groups of animals or bacteria etc. Similarity characteristic refers to the similarities in two aspects, not only the similarity in function. Merely function similarity might be superficial or shallow, even vague and not scientific. System dynamics holds that when constructing system model, only simulating the function of system is far from enough, the structure of system must also be truthfully reflected. Only this kind of model can possibly describe the objective world more objectively and scientifically.

System dynamics holds that there is no unbridgeable gap between different fields. It's very common that one function corresponds to multiple structures. There exists the possibility of structure-function simulation, i.e. the possibility of one simulating the function and behavior of one kind of structure with another kind of structure. This is the foundation of creating model to simulate systems. System dynamics has, for a long time, bridged across the system laws and theories of different fields according to this. Just based on the similarity characteristic of systems, we can find various similar feedback machanisms and similar units and links in various absolutely different systems. System dynamics utilizes feedback loops to integrate the basic structures of a system; applies various feedback mechanisms and similar units and links to describe the model of systems and holds that state variables, changing rate of state, certain logical functions and delay links etc. are variables and functions universally existing in various systems. Utilizing these units and links, it is possible to create a system dynamics model which can portray the real system both structurally and functionally.

The characteristics of a complex system

The theoretical ways of system dynamics are very applicable to studying and handling problems in such complex systems as socio-economic-technology-ecology and biology. It is extremely necessary for researchers of system dynamics and modelists to understand the characteristics of these complicated systems. All these complicated systems share the characteristics of non-linearity, high-order and multiloop. So they appear to have complicated dynamic characteristics.

The following is the main characteristics based on socio-economic systems.

(1) Counter-intuitive. Without exception, all the complex systems are found to be counter-intuitive. Since most daily life and thinking processes are about the experience of first order negative feedback system, people always relate a matter's causality with time and space closely. The simple causality, however, no longer exists in a complex system, in which causality and time and space are usually seperated. Therefore, a complex system is more elusive than simple one. People very often go astray by relating some symptoms of a system with a certain cause which seems to be close in time and space, but actually no causality exists between them. In a complex system, almost all the variables are highly related, but there is no great point in distinguishing the cause and effect from the angle of time-correlation. Therefore, it is unnecessary to put too much emphasis on statistics and correlation analysis. To judge from the view of confidence with in which people concern, most of the intuitve methods which seem to solve complex socio-economic problems are incorrect or ineffective.

(2) Insensitivity to the variable parameter, resistance to policy change and leverage point of policy. Due to its non-linearity,

the behavior modes of a complex feedback system model will remain almost unchanged if most parameters of the model are changed, or even if some parameters are changed several times greater. This can be proved by the circumstances in a socio-economic system, which is familiar to all of us. For example, different continents have different social tradition, socio-system, and raw material conditions, but the socio-economic development laws and the problems that different countries came across during the economic development are very similar. This shows the insensitivity of a complex system to parameter change.

What is called policy is those laws which describes how information is used to determine actions. It consists of the system structure (namely the choice and use of information source) and the parameters (namely the degree determining the influence of information and the strength of actions). The reason why a complicated system presents its resistance to policy change lies in its counter-intuitive and its insensitivity to parameter change.

However, another important characteristic of a complicated system must not be neglected. In most system, some parameters can be found, whose change greatly effects the system action (namely leverage point of policy). Whenever the policy through these leverage points is changed, its effect will be transmitted radially and the behavior of the system will be changed. These leverage points of policy are not obvious. They can only be determined through the process of scientific examination.

(3) The contradition of long and short period effect.

Usually, the influence and effect of long and short term caused by changing the internal structure and parameters in a complicated system by means of non-linearity are contrary to each other. Such examples are not rare. e.g. Twists and turns herald success, or superficial success is followed by collapse. Take accumulation rate for another example. Accumulation rate refers to the important synthetical index that reflects the accumulation scale and national economics. Proper accumulation rate is very important. The national economics can be increased by keeping a high accumulation rate (e,g. 30%) for several years, but this will lead to the serious imbalance of accumulation and consumption, industrial structure, and the reduction of accumulation effect. If things continue in this way, the national economics will fall into dilemma. So it's especially important to weigh the unity of opposites between short-term and long-term interests when we plan and control the developments of a complicated system.

SOME IMPORTANT VIEWS ABOUT THE SOCIO-ECONOMIC AND MANAGEMENT SYSTEMS

Most socio economic system are not stable

There is a one-sided view that regards socio-economic and management systems as stable and therefore can be handled by the methods which are employed to solve stable systems.

As a matter of fact, most of these kind of systems present the characteristics of unstable systems. Only a few systems are stable systems.

Linear analytical approach

Since most factors of this kind of systems are of non-linearity and all their behaviors have the feature of non-linearity. What's more, the variables in a system fluctuate in a wide range and the linear analytical methods of "small signal" are no longer applicable.

Views on the "prediction"

Social, economic, and management systems are intrinsically complicated non-linear stochastic systems. System dynamics models can only "predict" the trend, features, and characteristics of the future behavior of this kind of system, but it can not "predict" specific future events and actions. In fact, this assertion is fit for all kinds of models.

The optimal solution of system parameters

Generally speaking, only simple systems have optimal solutions of parameters. Complex non-linear systems may have sub-optimal solution, but not the optimal solution, or that we can't find it.

System structure and the degree of accuracy of parameters

System dynamics considers it much more important to have the correctness of a model structure than the degree of accuracy of parameters. If the structure of a model is incorrect, it would be of no avail to have a exactly accurate parameter. If a model ignores the correctness of its basic structure and pursues the degree of accuracy of individual parameter, no matter what kind of socio-economic model it belongs to, it is unacceptable.

CONCLUSION

System dynamics, which is a branch of system science, is a new comprehensive discipline to understand and solve the problems of systems. It is also a scientific field that links up natural sciences and social sciences.

With the help of computer simulation, we can quantitatively study the problems of systems by analyzing systems, building system dynamics models according to the theories, principles, and methodology of system dynamics.

The model simulation of system dynamics is a structure-function simulation. It is most suited for studying and analyzing the dialectical unity of opposites between the structure, function and action of information feedback mechanism.

Due to its non-linearity, the complex high-order time-varying systems usually present dynamic characteristic that are counter-intuitive.

Our attention should be paid to the features of complicated nonlinear systems.

The models of system dynamics are the lab of actual system. In order to find the ways to solve system problems and obtain more abundant and more profound information, we can analyze systems by the simulation of models. The process that system dynamics uses to solve problems is in essence the process of seeking the sub-optimization. Its final goal is to find the sub-optimal or comparatively better structure of a system which has a comparatively better function.

One outstanding advantage of system dynamics is that it can handle problems of high-order, non-linear, multi-feedback, and complicated time-varying systems.

On the basis of system dynamics and by absorbing the quintessence of other system subjects, a more effective theory and mehteodology of system thinking, computer simulating and sub-optimizing, which are to solve complex non-linear systems, can be found, and we are looking forward to it.

Since system dynamics can quantitatively analyze the internal relationship of structure and function of complex systems and their characteristics, probably it will become a bridge and an effective tool to build up complete system theories.

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