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Original Article

Application of System Dynamics in Public Policy

Mohammad Akbar Shikhzadeh*[1], Rasul motazedian[2], Muhammad moradzahipour[2], Muhammad Ghasem Mirzaei[3]

[1]Master of Information Technology Management, University of Sistan and Baluchestan, Iran
[2]Master of Public Administration student at Allameh Tabatabayi University, Tehran, Iran
[3]Tourism Management graduate student at Allameh Tabatabayi University, Tehran, Iran

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ABSTRACT

Today our world is a world of accelerating change. It is a system in which we, as the components, play our own roles whether consciously or unconsciously. The only way to understand the connections and interdependencies of such a huge, complicated and dynamic system is to have a systemic point of view. And public policy which is considered as inherently complicated field must be dealt with a COMPLICATED manner. In this regard, the dynamics of the system arises as a multidisciplinary field. System dynamics is a perspective and a set of conceptual tools that enable us to understand the structure and dynamics of complex systems. In this paper, we will pay attention to the relationship between public policy and the global view of system dynamics, how to solve complex problems in the process of policy-making by the means of dynamics of the system, namely the process of dynamic modeling, the causal loop diagram, to convert the causal loop diagram into a cumulative flow diagrams and simulation of models by means of computer software, and eventually the potential contributions of systems techniques to matters related to public policy.

Keywords: Systemic thinking, System dynamics, Policy.

Introduction

21st century will be of great importance for mankind. Increase in population in some areas of the world, technical innovations, values transformations, changes in political, economic and strategic borders has turned this century into a special period of time. Confrontation with the new century involves complex and new decisions and policies and if policy-making system cannot adapt itself with time changes and complexities, all beneficiaries will be damaged (Alvani and Sharifzadeh, 2011: 175). Therefore, it can be said that public policy-makings a naturally complex field of study (Kennedy, 2011). When we face complex issues, we must use an appropriate language (Sangeh, 2009: 100). Ashebi calls this important principle "need for diversity law"(Ashebi, 1963: 86).

System dynamism which is based upon the modern theory of nonlinear dynamics and control theory is a technical tool which can help managers and policy-makers with solving organizational and social problems. System dynamism uses formulas, mathematical rules at a minimum level and deals with issues with insight, spiritual understanding and techniques for thinking. Real models especially in public policy processes are usually complex and non-linear and many mathematical tools have application limitations. System dynamism enables us to use a strong technical platform for development of insight and conceptual understanding of complexity and dynamism (Sterman, 2007).

Theoretical Roots

Linear and mechanical thinking must be replaced by non-linear and organized thinking which is known as systematic thinking in order to understand the origin and solutions to modern issues. Nonlinear method believes that totality is super (Ahmadvand and Arab, 2009). System dynamism approach which is a branch of systematic thinking is a method for analysis, solving problems and system simulation. This technique is a method for analyzing systems and complex issues. This technique uses computer simulation which was developed in 1960s by Fourester in MIT University. This technique is a suitable method for analyzing systematic elements which have causal relations, mathematical and logical infrastructure, temporal delays and feedback rings (Momeni and Morovvati Shrifabadi, 2006). This technique was formed in industry and commerce and then was introduced to urban management (Ghoddusi, 2003). However, it is being used in many scientific arenas (Hamidizadeh, 2000: 34).

Definition

System dynamism is a philosophy which has turned into scientific and practical fields for dealing with real world conditions. It deals with situations in order to understand system's general structure and behavior (Kennedy, 2011). System dynamism lacks a unanimously accepted definition. For example, the following is a definition:

It is an exact method for describing, exploring and analyzing complex qualitative systems in terms of processes, information, organizational borders and their strategies which facilitates simulation, and quantitative analysis for designing structure and controlling system (Wolsten holme, 1990).

Advantages of using system dynamism approach are as follows

This process provides a better understanding of system structure due to critical and analytical approach in modeling process. Executing team tries to improve a model of reality continuously. System simulation usually results in a new understanding of behavior and structure and facilitates preparation of more complete models in the next round. This is a great advantage for models of system dynamism in which system model is prepared in the form of white box (meaning causal relationships among elements are explained). In contrast, mathematical models usually present a black box of problems (mathematical and statistical relationships between variables without explanation of behavioral structure).

system dynamism models facilitate inserting qualitative and quantitative variables simultaneously in system. This is an important advantage which cannot be found in mathematical models. Fourester believed that system dynamism must be based upon an empirical approach and based upon computer simulation. This approach helps with writing inexact equations for qualitative variables and numeral simulation of them so that the influence of these variables on system is understood (Cualfield, 2002).

Characteristics of complex systems

Dynamic complexity forms due to system characteristics like: dynamism, strong interaction, controlling with feedback, non-linearity, historical dependence, self-organization, matching, resistance against policy and balance(Sterman, 2007: 42-44). However, dynamism and feedback are more important than all. Issues which are studied in system dynamism researches must have at least two characteristics:

1. Dynamism: dynamism means it can be defined based on changing values over time, like increase in the number of resignation requests in an organization, reduction in customers' requested products and … (FartookZadeh, 1992: 1).
2. Feedback: our actions influence on each other due to deep relationship between system rings. Our decisions make changes in the world and nature and prompt others; therefore, new conditions influence on our next decisions; therefore, dynamism is resulted from these feedbacks (Sterman, 2007: 42).

Four items must be clear if we want to have a good understanding of the structure of a system:

System border

Feedback rings network

Surface, rate and auxiliary variables

Lever points (Jackson, 2012: 92).

System border must be specified in a way that it contains all important and interactive elements and keep all factors which have not decisive influence on the system outside the border. Here, it is assumed that all system dynamic behaviors are resulted from interaction of elements inside the border. Feedback rings are identified inside border and their natures are determined in terms of being positive or negative or interaction. The base of feedback rings is rate, flow, surface or cumulative. Using these models, managers can measure the influence of their interventions and decisions using models. Furthermore, managers will be able to recognize lever points or parts of the system which will yield the best result if actions are focused on them. These actions may be in the form of disconnecting some communications or adding new feedback rings.

Development of dynamic model

There is no instruction for making sure that the model is successful. In other words, modeling is a creative process and there are different steps and styles for doing them (Sterman, 2007). The following logical approaches are used for modeling:

Mapping system structure

Systems dynamism includes different tools for specification of model border and representation of its causal structure. These tools include causal diagrams and state and flow maps (Sterman, 2007).

Cause and effect diagrams

Cause and effect diagrams is a tool for sketching causal relationships among a set of variables (or factors) involved in a system. The main elements of cause and effect rings are: variables (factors) and flashes (relationships). A variable is a condition, action or decision which can influence other variables or can be influenced by other variables. Variables can be in quantitative form (measurable) like profit, productivity or employees' absence rate, or it can be in qualitative form like motivation, trust, being tired, validity and mental image of people of one issue. Direct measurement of qualitative variables is not easy and therefore, one of the advantages of sketching cause and effect diagrams is incorporation of these kinds of variables in modeling process.

Table 1. Steps for systematic modeling process of problems

Stages	steps
Problem structuring	Identification of issues which worry managers Collection of primary data.
Modeling causal rings	identification of main variables Sketching system behavior diagrams over time (reference model) Development of cause and effect diagrams Analysis of rings behavior over time Identification of general models (Archetypes) governing the system Identification of key lever points Development of strategies for intervention in system
Dynamic modeling	Formation of a rich map or image of the system Definition of the types of variables and sketching flow diagrams Collection of information in detail Development of a simulation model Simulation of equilibrium condition of system Reproduction of system reference behavior Model validation Model sensitivity analysis Designing and analyzing policies Development and experiment of strategies
Scenario modeling and planning	Designing general sphere of system scenarios Identification of key motivators in changing and important uncertainties Simulation of scenarios with model Evaluation of stability in policies and strategies
Organizational implementation and learning	Preparation of a report and presenting it to managerial team Transfer of results and evidence to beneficiaries Application of game tool for evaluation of imaginary models and facilitation of organizational learning process

Reference :(Ghoddusi, 2003: 52)

The second element of cause and effect diagrams is relationship among variables. An arrow or relationship shows causal correlation between the two variables. For example, increasing advertisements can increase demand and higher price results in demand reduction.

When causal relationship between two variables is detected, it is necessary to specify the kind of relationship between them. In general, two kinds of relationship can be specified between two variables:

Two variables move in one direction;

Two variables move in opposite directions.

In other words, if an increase (decrease) in variable X results in increase (decrease) in variable Y, both variables move in the same direction. In contrast, if an increase (decrease) in variable X results in reduction (increase) in variable Y, both variables move in opposite directions. In relationship arrows between variables, relationship type 1 has been indicated with positive sign and relationship type two has been indicated with negative sign.

b) Causal rings

A causal ring is a conceptual tool which explains dynamic process in which a chain of causal relations form a closed set of relationships and are finally attached to the first variable (cause). When variables are attached to each other in a closed path a causal ring is formed. Therefore, in a causal ring, we must reach the variable we started from. Theoretically, all variables in this chain can be starting variable. This closed ring is an important element in system structure which is called feedback. Feedback means changes in one variable will finally influence on its final value. Feedback-based attitude differs from linear attitude in which relationships between two variables are one-directional. Feedback in rings forms behavioral models in ring which can be divided into strengthening and equilibrium rings.

Strengthening rings: these rings are positive feedback systems. These kinds of rings can express increasing or decreasing behavior. For example, all loans which must be repaid according to a specific interest rate have strengthening behavior. As loan amount increases, it will have more interest and more interest increases total liabilities. In contrast, when a company has low ability, its profit-making will be low and lower profit decreases investment in improvement of internal quality. In this case, system efficiency will be reduced. These kinds of positive rings which move system towards negative points are called flawed or Satan rings. Negative feedback in these kinds of rings increases negative feedback as we increase distance from system from goal point and direct system towards goal point. In various systems around us, all types of equilibrium rings can be observed. In human body, there are different equilibrium rings for adjusting elements in blood and body temperature. In daily life, Thermostat is a kind of equilibrium ring (Sangeh, 2009).

c) Flow diagrams

Cause and effect diagrams provide an imaginary understanding of system structure but these diagrams are not enough for investigation of system behavior over time. In order to have a better understanding of system behavior we need to formulate relationships between system variables and use computers to simulate variables values over time. Floe models variables in systems dynamism are divided into 3 main groups:

State variables: these kinds of variables are related to elements in system whose values form in a period of time. For example, a company's capital is a state variable because this variable is the cumulative sum of all previous investments which has formed over time. Usually, variables which show the average of a variable over time are state variable, like average sales of a company or employees' average. State variables indicate conditions in which the conditions remain unchanged if no change takes place in system. Therefore, a simple method for identification of these kinds of variables is that their values can be determined in each moment of time. In graphical diagrams, these variables are shown by means of a rectangle.

Rate variable:

Each state variables change by several rate variables. Rate variables show change value in one variable over time. For example, employment rate is a rate variable which increases state variable value (total human force of the organization). Therefore, human resource redundancy rate is also a rate variable which reduces state variable (total organizational human resource).

Auxiliary variable:

These kinds of variables indicate coefficients which determine relationships between other variables. For example, tax rate, investment rate, life-expectancy and lifetime are samples of auxiliary variables in dynamic models. Usually, exogenous variables in system are indicated by these variables (Ghoddousi, 2003).

Main stages of a dynamic system

Each dynamic system has three basic stages: 1) conceptual concept, 2) quantitative stage, 3) analysis and evaluation stage.

1. Conceptual stage: in this stage, modeler explains backgrounds and signs of a problem and depicts internal variables behavior, clarifies modeling goal, sketches closed limitation of system and finally, the product of this stage is the framework of the model. Steps of conceptual stage of dynamic modeling are as follows: statement of problem, dynamic hypothesis, formulation, model testing, design and evaluation of policy.
2. Quantitative stage: in this stage, overall framework which was depicted in the previous step approaches to real shape of a phenomenon. Modeler prepares to put the model into action using simulator software with determination of the type and value of each of variables. In this stage, mathematical relationships between variables which are inside system border are inserted into Venism software.
3. Analysis and evaluation stage: each dynamic hypothesis returns to conceptual stage after covering quantitative stage and computer implementation and becomes more exact in other parts of experiment and evaluation. Usually, modeler's awareness of the problem increases in each repetition time. In fact, system dynamism studies start from primary recognition and are continued with more recognition. Vensim software facilitates changing a variable's value and presents its influence on other variables (Saeedi and Shabzendedar, 2011: 150-151).
3. Research background of using systems dynamism approach in public policy.
4. Potential contributions of systems techniques to issues related to public policies:
5. Better understanding of government nature and issues related to public policy policies;
6. Ability to develop government theories;
7. ability to model public policy issues policies and evaluation of substitute competitive solutions;
8. Ability to model specific issues of public policy and evaluation of substitute competitive solutions;
9. Ability to consider numerous shareholders which may take part in public policy;
10. Ability to confront complex nature of issues with which government faces and are concentrated by public policy;
11. Ability to model influences of policy resistance in public policy, which are able to model and describe conditions in which events seem worse and result in defeat of policy.

12. Ability to produce models which are implementable widely (Kennedy, 2011: 130).

Table 2. Adetailed classification of studies conducted on SD influence on public policy

Special issues of public policy	General issues of public policy	approach
Frances et al. (1994), Geyer (1995), Woodhead (2001), Swanson (2004), Taylor(2004), Thompson(2004), Dangerfield(2005), Mabey (2005), Ratnarajah (2005), Turke (2006), Wolstenholme et al. (2004), Wolstenholme et al. (2005)	Forrester (1969), Meadows et al. (1972), Forrester (1973), Forrester (1995), Barlas and Diker (1996a, b), Forrester (1989), Galbraith (1989, 1998a, b, c), Kennedy (1999), Bell et al. (2000), Olaniyi et al. (2000), Curram (2002), Forrester (2002), Andersen et al. (2003), Kennedy and Clare(2003), Barlas and Diker (2000), Virtual University (2005a, b), Dudley (2004), Mabey et al. (2004), Bell et al. (2005), Kennedy (2005), Lacey (2006)	SD

Reference: (Kennedy, 2011: 130)

Conclusion

In this paper, the authors tried to present an appropriate and systematic model for solving complex and multi-disciplinary issues in the present world especially in the process of public policy because solving such issues with the present linear and mathematical methods is difficult and the present methods will not yield real results in all cases. Therefore, one of the suitable methods is using system dynamism. In system dynamism, imaginary models, causal relationships, minimum equations, mathematical assumptions are used and causal relationships are converted into accumulation and flow diagrams and finally the model is simulated by means of software applications like Vensim and real world is investigated in a virtual model. System dynamism is important because modeler can increase the number of parameters and also change parameters in short-term and long-term period and it can be a powerful tool for managers and policy-makers. Furthermore, because problem is investigated generally, its results will be beyond case studies for each element. To be short, system dynamism is an effective step in systematic approach for solving complex models in policy-making processes. System dynamisms can transform approaches to complex policy-makingissues .in other words, changing paradigms of approach to system dynamisms is a factor in correction of structure of decision-making.

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