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Dynamic Axiomatic Design (DAD): Applying the Independence Axiom in the Design of Social Systems

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Abstract

Compared with mechanical systems (fixed and flexible systems), social systems are more dynamic and complex. Because of human participation and interdependence, social system behaviour is not easily predictable, and the Independence Axiom cannot be easily applied. In this work we take time as a variable and adopt the dynamic axiomatic design (DAD) to account for the dynamic nature of social systems.

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Keywords: Independence Axiom; dynamic systems; social systems

1. Introduction

Systems range from very simple to very complex. There are numerous types of systems. For example, there are biological systems (the heart, etc.), mechanical systems (thermostat, etc.), human/mechanical systems (riding a bicycle, etc.), ecological systems (predator/prey, etc.), and social systems (groups, supply and demand, friendship, etc.) [1].

There are differences between mechanical systems and social systems. The former describes structures where tolerances of parts change over time due to damage, wear, creep, and other phenomena, environmental conditions (weather, vibration, etc.) [2]. Trends of changes are predictable. However, in the case of the latter, human participation and interdependence make the predictability of system behaviour difficult [3].

Human behaviour is structurally highly complex and changeable in time scope. Consequently, a human being is perceived as a psychosomatic unit with cognitive capacities embedded in a social environment [4].

Complex individual human characteristics allow for and are reinforced by interactions among individuals. These lead to a new level of system. a new pattern of organization: social systems. Based on Boulding's hierarchy of systems complexity (see Figure 1) level 4 is defined as that of social organization.

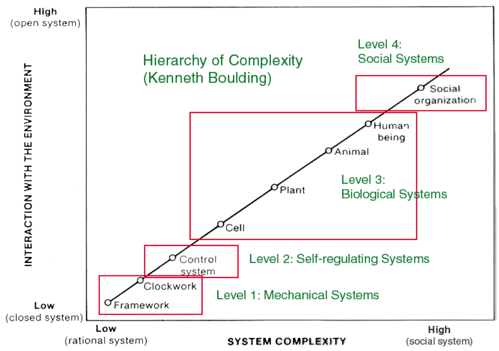

Figure 1. Boulding's hierarchy of system complexity

Social structure has been identified as: the relationship of definite entities or groups to each other, as enduring patterns of behavior by participants in a social system in relation to each other, and as institutionalized norms or cognitive frameworks that structure the actions of actors in the social system [5, 6].

Society systems constitute an adaptive network with "intelligent vertices", us as individuals [7]. For the general social system, as there are not clear relationships between the "inside" and the "outside" and between the system itself and

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its environment. As the boundary between the inside of the system and the outside is difficult to define, it is hard to analyze the effect of input on the output [8].

A social system is complex and dynamic. This indicates that human society will remain beyond our predictive capacities for many years to come [7]. Complexity theory has tended to focus on natural systems, but has been increasingly applied to social systems [9, 10].

Human behavior is influenced by physical, emotional, cognitive and social factors, it is highly intricate [4].

Suh distinguishes between fixed systems and flexible system [11]. In another work, Thompson and Doroshenko explored some of the issues associated with coupling and conflict in time in formal design theories. They discussed different types of time varying designs and time-dependent conflict and coupling [2].

Complex human characteristics both increase and decrease the potential for coping with uncertainty and for predicting future system states and impacts. Therefore researchers must be careful when designing social systems, and consider the type of relationship between functional requirements (FRs) and design parameters (DPs) with certainty and uncertainty environment and time of scope. Dynamic axiomatic design (DAD) can be used as a practical procedure to face probable changes happening in social contexts. This study aims at studying the degree of uncertainty and its relationship with the time span in varied social contexts. As a second objective, it also aims at studying the techniques appropriate to each context.

2. Literature review

Social systems may be seen to influence important systems including the economic system, legal system, political system, cultural system, and others. Family, religion, law, economy and class are all social structures. The "social system" is the parent system of those various systems that are embedded in it [12].

Dynamic systems is a recent theoretical approach that grows directly from advances in understanding complex and nonlinear systems in physics and mathematics, but it also follows a long and rich tradition of systems thinking in biology and psychology. The term dynamic systems, in its most generic form, means systems of elements that change over time. The more technical use, dynamical systems, refers to a class of mathematical equations that describe time-based systems with particular properties. The value of dynamic systems is that it provides theoretical principles for conceptualizing, operationalizing, and formalizing these complex interrelations of time, substance, and process [13].

Dynamics is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering. As we apply these tools to the behavior of human as well as physical and technical systems. System dynamics draws on cognitive and social psychology, economics, and other social sciences. As we build system dynamics models to solve important real world problems [14]. Figure 2 indicates modern dynamic views of change [15].

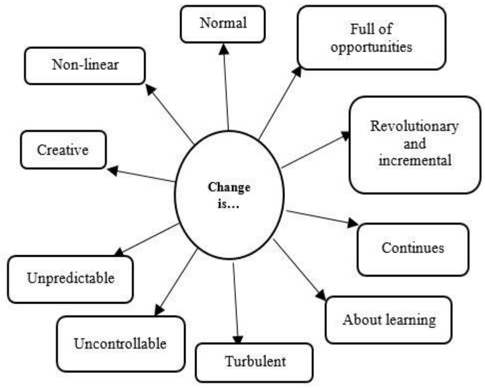

Figure 2. Modern dynamic views of change

The most complex behaviors usually arise from the interactions among the components of the system, not from the complexity of the components themselves [14].

Axiomatic design (AD) is an innovative method for solving the design problems in a rational manner. It provides an efficient framework to guide the designers through the design process and reduce much of the waste associated with the trial and error method [16].

AD methodology has been applied to various application areas from product design to decision making since it was proposed by Suh in 1990. Some successful applications of AD methodology are as follows: System Design; [17, 18], Manufacturing System Design; [19, 20], building systems [21, 22], transportation systems [23], educational systems [11, 24], and health care systems [25].

It is often assumed that all the experts are able to provide relationship degrees between of FRs and DPs. However, in dynamic systems this is not always possible because of time pressure, lack of knowledge and incomplete information, decision maker's limited expertise on the field dealt with, or incapacity to quantify the relationship between them. Thus, an expert might decide not to guess the preference values in doubt to maintain the consistency of the values already provided [26].

For decision makers, it's very essential that they are able to recognize the system components and decide based on their relationship in the real world.

3. Independence axiom in dynamic system design

When design matrix A is a square-diagonal matrix, the design is called uncoupled. An uncoupled design is a one-to-one mapping. Another design that obeys the independence axiom, although with a known design sequence, is called decoupled. In a decoupled design, matrix A is a lower or upper triangular matrix. The decoupled design may be treated as an uncoupled design when the DPs are adjusted in some sequence conveyed by the matrix [27].

A violation of the independence axiom occurs when an FR is mapped to a DP that is coupled with another FR. Such a practice creates a design vulnerability called coupling, which implies a lack of controllability and adjustability by both the design team and the customer [28].

Figure 3 shows these design categories according to the independence axiom.

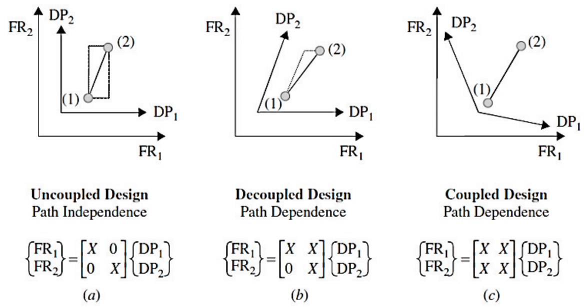

Figure 3. Design categories according to the independence axiom [31]

As it is mentioned for axiomatic design above, the relation matrix consists of 0 and X elements. Those symbolize whether there are relations between FRs and DPs or not. If there is a relation it is depicted by X in the relation matrix [29]. But in the real world, especially in sociality and management issues, the relationships between FRs and DPs in various time periods are influenced by many factors and are different because of their more complicated nature. Figure 4 shows that the effect of DPs on FRs is constant in the ranges of time and can be categorized into couple, decouple and uncouple.

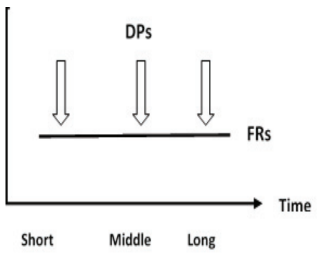

Figure 4. Effect of DPs on FRs in the range of time for physical and mechanical system

Figure 5 indicates that unlike physical and mechanical systems, the effect of FRs on DPs are changing during the time and this change can be ascending, descending or constant.

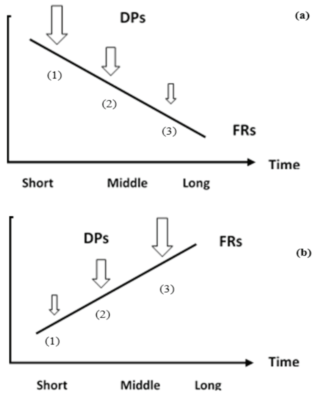

Figure 5. Effect of DPs on FRs in the range of time for dynamic systems

Our DPs alter our environment, leading to new DPs, but also triggering side effects, delayed reactions, changes in FRs and interventions by others. These feedbacks may lead to unanticipated results. In DAD mapping relation between FRs and DPs is changeable because many factors influence to this relationship according to Figure 6:

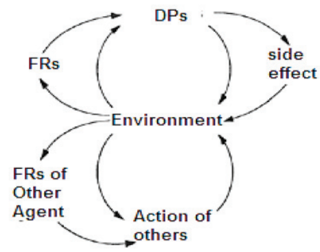

Figure 6. Dynamic relation between DPs and FRs

In addition, for another two domains of the design world, the relationship is dynamic in time scope. Thus, in new approach Dynamic mapping between the main domains according to the Figure 7:

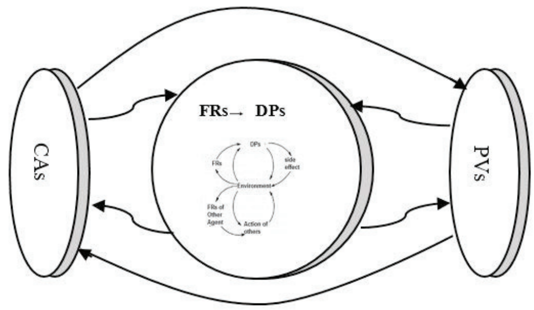

Figure 7. Dynamic mapping between four domains of the design world

AD emphasizes the idea that the relationship between different parts has a stable pattern. As a society's structure may determine its flexibility, capacity to change, and many other factors, DAD emphasizes the idea that the relationships between different parts have a variety of relationship patterns as relationships between different entities or groups or as enduring and relatively variation patterns of relationships with different functions, meanings or purposes.

The domain of FRs and DPs show that the relationships between them are under the influence of the decision making environment that the future environment can be certainty or uncertainty. Based on the environment type, crisp, probability, fuzzy and grey system theory can be used.

Currently, the theoretical studies of uncertain systems have been widely applied in all areas of natural science, social science, and engineering, including aviation. Probability mathematics, fuzzy mathematics, and grey systems theory are three frequently seen research methods employed for the investigation of uncertain systems. Fuzzy mathematics emphasizes the investigation of problems with cognitive uncertainty, where the research objects possess the characteristics of clear intension and unclear extension.

Probability and statistics study the phenomena of stochastic uncertainty with emphasis placed on revealing the historical statistical laws. They investigate the chance for each possible outcome of the stochastic uncertain phenomenon to occur. The focus of grey systems theory is on the uncertainty problems of small samples and poor information that are difficult for probability and fuzzy mathematics to handle. It explores and uncovers the realistic laws of evolution and motion of event and materials through information coverage and through the works of sequence operators [8]. Based on what is discussed above, we summarize the differences among these three most studies subject matters in Table 1.

Table 1. Comparison between the three methods of uncertainty research

Object	Grey systems	Prob. Statistics	Fuzzy math
Research objects	Poor information	stochastic	Cognitive uncertainty
Basic sets	Grey hazy sets	Cantor sets	Fuzzy sets
Methods	Information coverage	Mapping	Mapping
Procedures	Sequence operator	Frequency distribution	Cut set
Data requirement	Any distribution	Typical distribution	Known membership
Emphasis	Intension	intension	extension
Objective	Laws of reality	Historical laws	Cognitive expression
Characteristics	Small sample	Large sample	Experience

So regarding to the fact that relationships between FRs and DPs show its real effect in long term, the future of the environment is an uncertainty environment and in this environment, the type of relationship can also be expressed as a various shape.

Some of the scenarios decision in time scope are given in the Table 2. State 1 indicates the state of certainty between FR and DP the relationship between which is shown based on crisp numbers. Since society changes over time and it is not in a static position, automatically, the matrix indicating this relationship is also dynamic. Depending on the degree of uncertainty, one of the three states, i.e., states 2 to 4, have been added. Depending on the nature of context, each state has its own operators.

4. Practical Example

Indeed, the above scenario requires all experts to possess a precise or sufficient level of knowledge of the whole problem to tackle, including the ability to discriminate the degree up to which some options are better than others. These assumptions can be seen as unrealistic in many decision making situations, especially in social system because incomplete information available for experts for predict about changes in future [26].

As it is mentioned for dynamic social system design above in real case problems, sometimes, the relations between FRs and DPs can be unknown or uncertain. Moreover, there can be a little or indirect relationship between a FR and a DP such that this relation can be omitted by the designers or define the degrees of relations between FRs and DPs under uncertainty or fuzzy environment. In DAD, the type of relationship between the FRs and DPs must be specified based on period time and certainty condition, for example, according to research [30]. The main issues at a high-level decision process are: “to define a technical system; to define quality for the technical system; and to define the model for cost Figure 8 depicts those FRs and the corresponding DPs.

Table 2. Dynamic social system design

	Short time	Middle time	Long time	
State 1	$A=\begin{bmatrix} x & 0 & 0 \\ 0 & x & 0 \\ 0 & 0 & x \end{bmatrix}$	$A=\begin{bmatrix} x & 0 & 0 \\ 0 & x & x \\ 0 & 0 & 0 \end{bmatrix}$	$A=\begin{bmatrix} x & x & 0 \\ 0 & 0 & 0 \\ 0 & 0 & x \end{bmatrix}$	Certain state
State 2	$A=\begin{bmatrix} p(x) & 0 & 0 \\ 0 & p(x) & 0 \\ 0 & 0 & p(x) \end{bmatrix}$	$A=\begin{bmatrix} p(x) & 0 & 0 \\ 0 & p(x) & p(x) \\ 0 & 0 & 0 \end{bmatrix}$	$A=\begin{bmatrix} p(x) & p(x) & 0 \\ 0 & 0 & 0 \\ p(x) & 0 & p(x) \end{bmatrix}$	Probability state
State 3	$\tilde{A}=\begin{bmatrix} \tilde{x} & 0 & 0 \\ 0 & \tilde{x} & 0 \\ 0 & 0 & \tilde{x} \end{bmatrix}$	$\tilde{A}=\begin{bmatrix} \tilde{x} & 0 & \tilde{x} \\ \tilde{0} & 0 & 0 \\ 0 & 0 & \tilde{x} \end{bmatrix}$	$\tilde{A}=\begin{bmatrix} \tilde{x} & \tilde{x} & 0 \\ 0 & \tilde{x} & \tilde{x} \\ \tilde{x} & 0 & 0 \end{bmatrix}$	Fuzzy state
State 4	$A=\begin{bmatrix} \otimes x & 0 & 0 \\ 0 & \otimes x & 0 \\ 0 & 0 & \otimes x \end{bmatrix}$	$A=\begin{bmatrix} \otimes x & 0 & \otimes x \\ \tilde{0} & 0 & 0 \\ 0 & 0 & \otimes x \end{bmatrix}$	$A=\begin{bmatrix} \otimes x & 0 & \otimes x \\ \otimes x & 0 & 0 \\ 0 & 0 & \otimes x \end{bmatrix}$	Grey system state

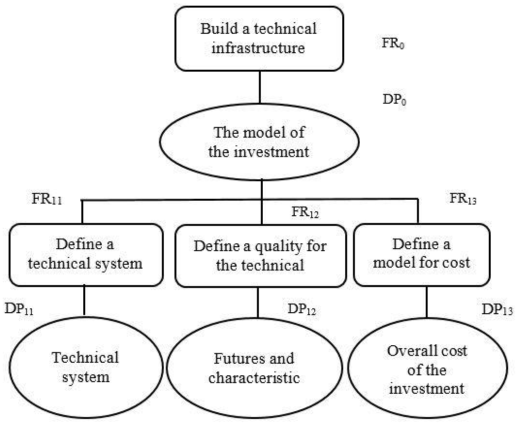

Figure 8. Investment decomposition

Equation (1) is the design equation in classic AD, which expresses the relationships between DPs and FRs, Where X denotes a relationship.

$$\begin{bmatrix} FR_0 \\ FR_{11} \\ FR_{12} \\ FR_{13} \end{bmatrix} = \begin{bmatrix} x & 0 & 0 & 0 \\ 0 & x & 0 & 0 \\ 0 & x & x & 0 \\ 0 & x & x & x \end{bmatrix} * \begin{bmatrix} DP_0 \\ DP_{11} \\ DP_{12} \\ DP_{13} \end{bmatrix} \quad (1)$$

AD emphasizes the idea that relationship between different parts has stable pattern of relationship (Equation 1).

But if asking question of the experts in short, middle and long- term dynamical, according to Figure 5 in new approach design matrix relationship in point 1,2 and 3, respectively as follows:

$$\begin{bmatrix} x & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & x & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & x & x & \mathbf{0} \\ \mathbf{0} & x & x & x \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} \otimes x & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \otimes x & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \otimes x & \otimes x & \mathbf{0} \\ \mathbf{0} & \otimes x & \otimes x & \otimes x \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} \tilde{x} & \mathbf{0} & \tilde{x} & \mathbf{0} \\ \mathbf{0} & \tilde{x} & \mathbf{0} & \tilde{x} \\ \mathbf{0} & \tilde{x} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \tilde{x} & \tilde{x} \end{bmatrix} \quad (4)$$

DAD emphasizes the idea that the relationship between different parts has a variation pattern of relationship with different functions, meanings or purposes (Equation 2, 3 and 4). In the proposed approach, i.e., DAD, as we shift away from shorter time spans towards longer time spans, we should also move away from crisp numbers towards grey and fuzzy states.

5. Conclusion

Very simply, a system is a collection of parts (or subsystems) integrated to accomplish an overall goal (a system of people is an organization). Systems have input, processes, outputs and outcomes, with ongoing feedback among these various parts. If one part of the system is removed, the nature of the system is changed.

In mechanical system design (fixed and flexible system), the parts of system may be stable or change over time. In flexible systems, the tolerances of parts changes over time due to damage, wear, creep, and other phenomena. Environmental conditions (weather, vibration, etc.) can also introduce time dependent variance into a system and the trend of changes are predictable. In the design of these systems, humans do not play an important part. But, human beings are most often an integrated part of social systems and they are not just biological creatures. Human behavior is structurally highly complex and changeable in time scope. It is difficult to predict social system behavior because of human participation and interdependence. Over time, customers have developed new needs, or rather, they have become more demanding.

In the real world, particularly the world of social action, feedbacks often do not operate well. Today the rate of change in our systems is much faster, and their complexity is much greater. Dynamic complexity arises from the interactions among especially the human agent over time.

Dynamics is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering. As we apply these tools to the behavior of Human as well as physical and technical systems. System dynamics draws on cognitive and social psychology, economics, and other social sciences. Thus we build system dynamics models to solve important real world problems.

In decision making, situations where all experts are able to efficiently express their opinions over all the available options are the exception rather than the rule. The classical manner requires from all experts to possess a precise or sufficient level of knowledge of the whole problem to tackle, including the ability to discriminate the degree up to which some options are better than others, which can obviously be seen as unrealistic in many decision making situations, especially in social and management systems with dynamic sources of information.

Axiomatic design (AD) is an innovative method for solving the design problems in a rational manner. In classical axiomatic design, the relation matrix consists of 0 and X elements. Those symbolize whether there are relations between FRs and DPs or not. If there is a relation it is depicted by X in the relation matrix. Otherwise, the relation is denoted by 0.

In Dynamic approach, type of relationship between FRs and DPs must be specified based on time period and uncertainty condition. As a new approach, DAD deals with a dynamic environment. It is based on the supposition that the component parts of the social system dynamically interact with each other.

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