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SYSTEM DYNAMICS
A PRACTICAL APPROACH FOR MANAGERIAL PROBLEMS

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MANAGERIAL problems are becoming complex with the impending techno-socio-economic change. Managers find it difficult to cope with this complexity with traditional management approach based on mental models, intuition, experience and judgments. There is a pressing need to substantiate the manager's knowledge with tools of selecting and structuring information available with the manager, and to generate consequences with the help of formal models, so that working of the system can be better understood and policies can be improved. System Dynamics (SD) is a methodology that judiciously combines the traditional management with cybernetics and computer simulation so as to carry out sound policy analysis. System dynamics can usually be properly applied whenever problems can be expressed as variable behaviors through time. Therefore, system dynamics has been applied in many fields, among them medicine, law, urban studies, global studies, environmental studies, information science, literature, history, economics, finance, chemistry, physics, etc. This paper is an attempt to find out the specific areas in Business Management where SD can be applied effectively. Firstly; an attempt is made here to understand the methodology of SD. Secondly; a review of earlier research work is conducted to find out the various applications of system dynamics in the field of Business Management. The purpose of the review is to understand the needs to unravel the applications of SD in management, to identify the current research frontier and to study the future trend in this field. Finally; the paper highlights the problems in the various fields of Business Management, where SD can be applied effectively. It is hoped that this study is valuable and beneficial both to new researchers entering the field, in order to gain their interest, references and focus, and to experienced researchers, in order, perhaps, to identify new research opportunities and/or issues that intersect these researchers' past and current interests.

Introduction: System Dynamics

Managerial problems are becoming complex with the impending techno-socio-economic change. Managers find it difficult to cope with this complexity with traditional management approach based on mental models, intuition, experience and judgments. There is a pressing need to substantiate the manager's knowledge with tools of selecting and structuring information available with the manager, and to generate consequences with the help of formal models, so that working of the system can be better understood and policies can be improved. System Dynamics (SD) is a methodology that judiciously combines the traditional management with cybernetics and computer simulation so as to carry out sound policy analysis. A SD model organizes the structure, information flows and policies of a system in a computer model based on the cybernetic structure i.e., the cause-effect feedbacks in the system. System dynamics can usually be properly applied whenever problems can be expressed as variable behaviors through time. Therefore, system dynamics has been applied in many fields, among them

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medicine, law, urban studies, global studies, environmental studies, information science, literature, history, economics, finance, chemistry, physics, etc. This paper is designed to give a brief overview of the SD methodology in terms of its foundations, philosophy and conceptual framework and it also tries to demonstrate the areas where the system dynamics methodology can be applied effectively to solve the different managerial problems in the various fields and levels of Business Management.

Underlying Philosophy

In order to appreciate the actual methodology and its operational detail, it is good to understand the underlying philosophy on which the methodology is based. There are basically, two governing philosophies of life, viz. (i) Causal philosophy and (ii) Chance philosophy. According to the causal philosophy, there is always a cause behind an effect seen. The Indian philosophy is essential causal, which is deterministic in nature. The philosophy of Karma, which governs the life, is causal in nature according to which the fruits or effects obtained are an outcome of the Karma caused by an individual. Thus every event happening in the life can be tracked back in the causal chain and, in principle, some cause can be assigned for the happening of any event in the world.

On the other hand, the chance philosophy treats the events to be as chance happenings. The outcome of an event is not certain or deterministic rather probabilistic. Some action might result into many possible happenings according to some probability distribution. Thus any event in life can be assessed by the probability of its happening.

System Dynamics finds its roots essentially in the causal philosophy, though in a pragmatic manner it may be treated as a *system of chance and cause*. That is, define the model boundary upto a particular limit endogenizing the causal framework and treat the rest as exogenous inbuilding the chance phenomenon to a limited extent.

Why System Dynamics?

The justification for using SD for managerial problem solving and policy making can be provided by examining various requirements and matching the strengths of SD with them.

- SD is able to cater to the requirement of managerial systems and problems of providing a modeling framework that is causal, captures nonlinearity and dynamics, and generates endogenous behaviour.
- SD inbuilds the strengths of both the traditional management and management science in terms of information richness and scientific approach, and overcome their weakness effectively.
- SD uses the strengths of human mind and mental models and overcome their weakness by making a division of labour between manager and technology. It generates the structure with managerial inputs and simulates the consequences by using computer.
- SD uses multiple sources of information, i.e., mental, written and numerical in different phases of modeling so that the models are more contentful and representative.
- SD portrays bounded rationality by mapping the decisions functions and policy structures generated through mental models making effective use of information feedback theory and behavioural decision theory.
- SD provides microworlds for policy makers, enriches the policy debate by interplay of knowledge, information and maps generated using information feedback theory and behavioural decision theory. These provide a learning environment through which experimentation and classification of policy considerations can be facilitated and managerial policy making skills are enhanced.

SD models provide intermediate feedback to policy makers about the possible impact of a particular set of policies by simulating them, and analyzing behaviour of the system under different sets of assumptions. This results in the formulation of an improved policy profile for the organization. This provides an efficient and effective way of policy formulation and implementation. Figure 7 in Appendix-VII also shows the justification of using SD for managerial problems.

Why System Dynamic Modeling is Effective?
System dynamics modeling can be effective because it builds on the reliable part of our understanding of systems while compensating for the unreliable part. The system dynamics procedure untangles several threads that cause confusion in ordinary debate. The modeling process separates consideration of underlying assumptions (structure, policies, and parameters) from the implied behavior. By considering assumptions independently from resulting behavior, there is less inclination for people to differ on assumptions, with which they actually can agree, merely because they initially disagree with the dynamic conclusions that might follow. Figure 1, divides knowledge of systems into three categories to illustrate wherein lie the strengths and weaknesses of mental models and simulation models.

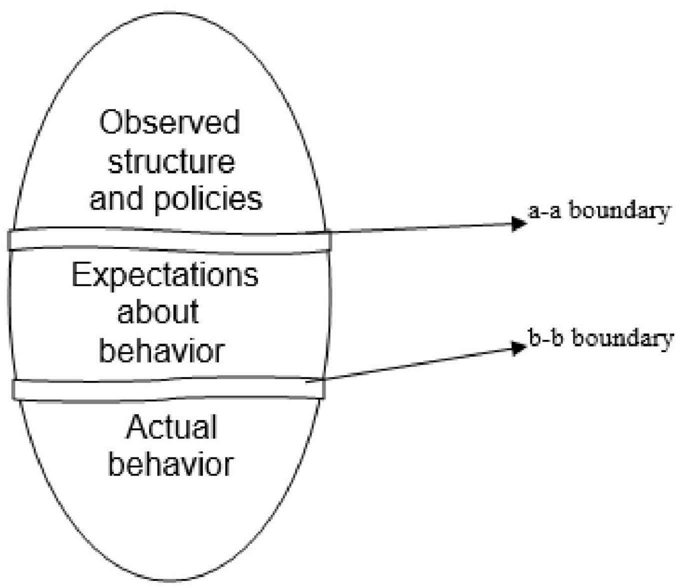

Figure 1: Three Categories of Information in the Mental Database

The top of the figure represents knowledge about structure and policies, that is, about the elementary parts of a system. This is local non-dynamic knowledge. It describes information available at each decision-making point. It identifies who controls each part of a system. It reveals how pressures and crises influence decisions. In general, information about structure and policies is far more reliable, and is more often seen in the same way by different people, than is generally assumed. It is only necessary to dig out the information, guided by knowing how structure is related to dynamics, that is, by using system dynamics insights about how to organize structural information to address a particular set of dynamic issues.

The middle of the figure represents assumptions about how the system will behave, based on the observed structure and policies in the top section. This middle body of beliefs is, in effect, the assumed intuitive solutions to the dynamic equations described by the structure and policies in the top section of the diagram. The center section of the diagram represents the solutions, arrived at by introspection and debate and compromise, to the high-order nonlinear system described in the top part of the figure. In the middle lie the presumptions that lead managers to change policies or lead governments to change laws. Based on assumptions about how behavior is expected to change, policies and laws in the top section are altered in an effort to achieve assumed improved behavior in the middle section.

The bottom of the figure represents the actual system behavior as it is observed in real life. Very often, actual behavior differs substantially from expected behavior. Discrepancies exist across the boundary b-b. The surprise, arising from the fact that observed structure and policies do not lead to the expected behavior, is usually explained by assuming that information about structure and policies must have been incorrect. Unjustifiably blaming inadequate knowledge about parts of the system has resulted in devoting uncounted millions of man-hours to data gathering, questionnaires, and interviews that have failed to significantly improve the understanding of systems.

A system dynamics investigation usually shows that the important discrepancy is not across the boundary b-b, but across the boundary a-a. When a model is built from the observed and agreed upon structure and policies, the model usually exhibits the actual behavior of the real system. The existing knowledge about the parts of the system is shown to explain the actual behavior. The dissidence in the diagram arises because the intuitively expected behavior in the middle section is inconsistent with the known structure and policies in the top section.

Which Managerial Problems should Use System Dynamics?

The application of System Dynamics (SD) methodology to the real life problem situations, particularly the managerial problems is the concern of this section. A brief review of the past applications of System Dynamics is reported in the next section. The various view points and features of SD are related to different problem solving steps i.e., (a) Defining the Problem,(b) System Conceptualisation, (c) Building the Model, (d) Simulation and Validation, (e) Policy Analysis and Policy Evaluation and (f) Policy Implementation In view of the successful applications made in the problem contexts in past and the features and philosophy of the SD methodology, an attempt is made to portray the basic characteristics of the managerial problems that justify the use of SD for their analysis. This leads to the identification of problem contexts at various managerial levels in the conventional management pyramid, both vertically and horizontally in various functional areas that might be successfully addressed by the SD modeling as shown in Figure 2.

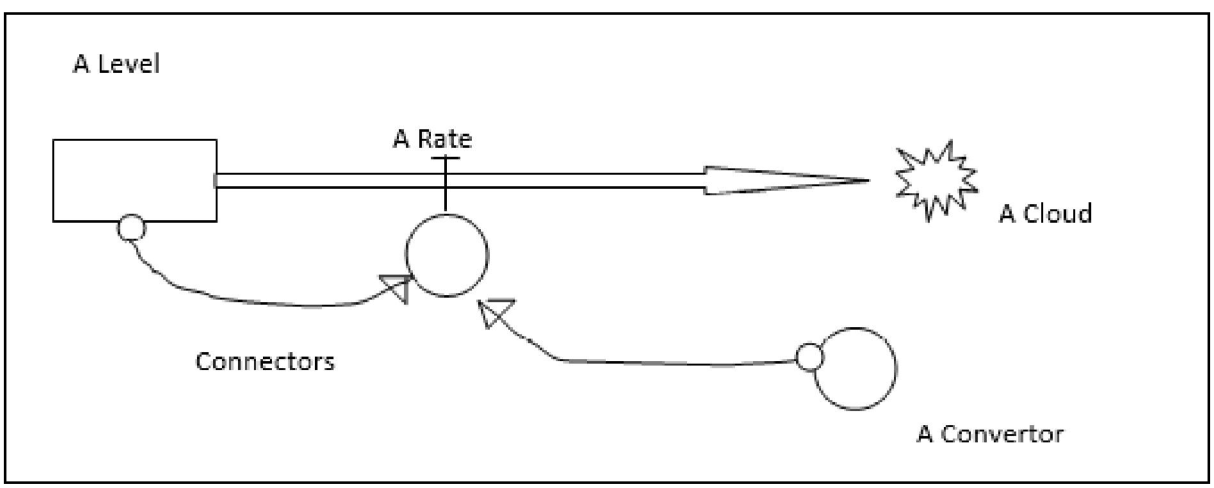

Figure 2: The System Dynamics "Language"

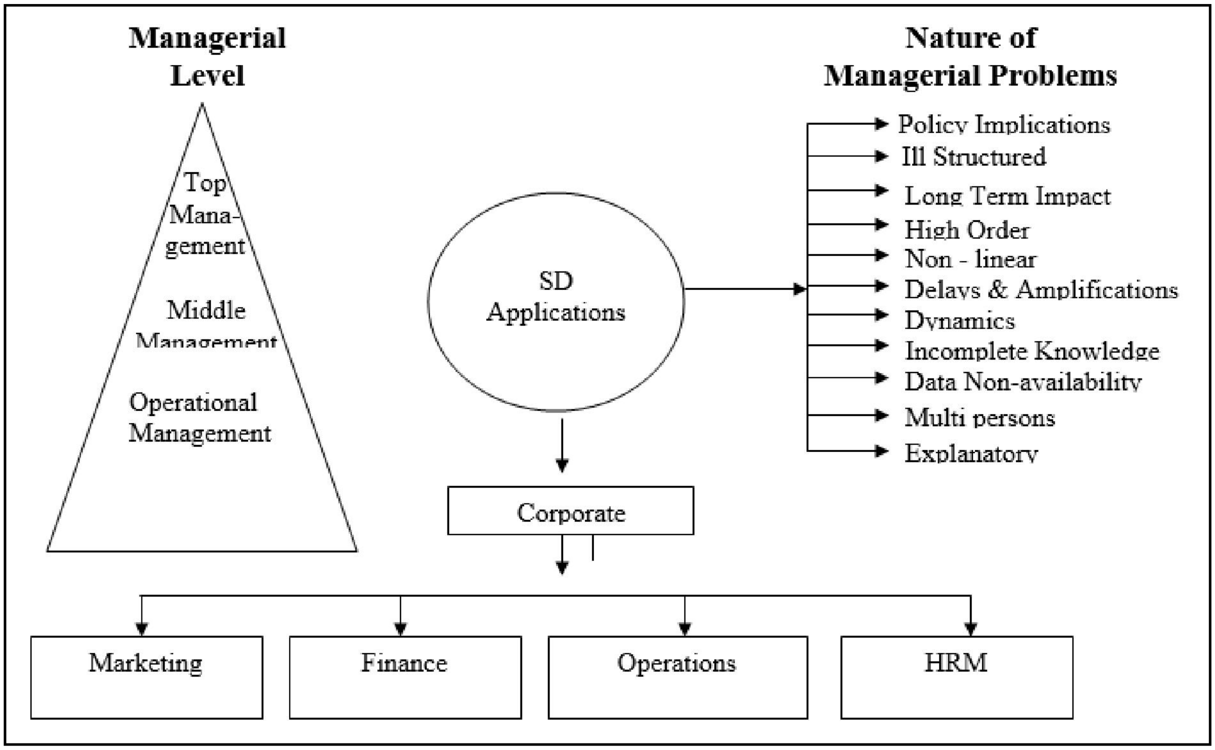

Figure 3: Managerial Problems for System Dynamics Application

Developments In India

The development of SD in India started in early eighties with mainly the work of Mohapatra at IIT, Kharagpur. The software package DYMOSIM was developed in 1985, and the "System Dynamic Society of India" was formed with its official journal "System Dynamic: An International Journal of Policy Modeling". The society organizes a National Conference every two years. SD has been approached from an integrative view point to interface it with other modeling methodologies, such as Physical System Theory. By Sushil at IIT Delhi and a software package named DYSBASE was developed to facilitate such interfacing. A succinct review of SD developments in India can be seen in Mohapatra (1991).

With the basic SD methodology attaining maturity it has now entered into its second phase of growth to enbroaden the paradigm by suitably interfacing it with other modeling methodologies so as to provide a pragmatic and practical approach for management support.

System Dynamic Paradigm

The problem situation for SD modeling can be identified by formal perpetual review; group discussion/ brainstorming; idea engineering; regular policy planning; policy reviews; and/or new policy formation. The next step is to carry out situation analysis. A background note about the problem situation is to be prepared and dynamic behaviour of interest is to be identified. The key variables are identified and their reference modes are developed to define the dynamic hypothesis. The modeling approach is determined by the combination of diagramming aids used in developing the model. The SD offers a flexible modeling methodology, which depends upon the problem situation; modeler and the software package used for modeling and analysis.

System Dynamics Language
System dynamics is a method of solving problems by computer simulation. Like many simulation methods, it offers the promise of less expensive learning. It is cheaper and faster to experiment with the effect of new policies on a computer model than on a real system with real people, equipment, and processes.

System dynamics incorporates features that make it especially useful for certain problems. System dynamics can model the effect of information feedback on the future direction of the model. For example, if the cycle time in a production process becomes excessive, management would typically intervene to make changes, while many process simulations would simply report that cycle time was continuing to grow. System dynamics handles this easily. To facilitate the use of information feedback, system dynamics carefully separates information accumulated about the state of the system and information fed back from that state to control the evolution of future states. These two key features enable a system dynamics model to address situations that evolve over time. Research indicates that people are often poor at solving such problems mentally. The language of system dynamics is simple (Figure 2). Levels (also called stocks) contain quantities describing the state of the system. If the model (or system) were stopped, each of these would continue to hold its quantity for observation. For example, the amounts of money in various financial accounts are typically levels in a financial system. In a typical system dynamics diagram, these appear as labeled rectangles. If the value of a particular stock is of no concern to the problem at hand, then the stock is shown as a cloud to indicate that it's outside the boundary of the model.

Rates (also called flows) are the inflows to and outflows from the various levels. These appear as labeled valves on pipes connecting levels. If the system were stopped, rates also stop. For example, the paying of interest into an account is a rate. If the system were frozen in time, there would be no flow of interest into accounts. Connectors and converters (also called auxiliaries) measure the quantities in levels and, through various calculations, control the rates. These appear as as lines with arrows and as circles. Management policies (the rules by which managers make decisions) are modeled by these calculations.

System Dynamics Modeling
System-dynamics modeling combines both quantitative and qualitative research techniques to provide a new framework for applied research. Building the Causal-loop diagram is only the first step in SD modeling. The next step is to validate the actual data over time that captures the effect evidenced by each attribute in the model to determine if the attribute behaves consistently as modeled. This validation ensures that the data and observations captured by the original model are not an aberration in the process. Once the model has been validated with historical data, it will be much more useful in identifying critical attributes and predicting the effect of changes in model attributes.

Systems Thinking
Systems Thinking is the mind-set that allows (and ultimately obliges) us to examine the world by consciously recognizing and formally exploring the systems of which it is made.

1. Systems are fundamentally dynamic in time. A static "snapshot" of a system reveals the size of the Stocks at that instant, but discerning the role of the Flows, or of the feedback loops that control them, requires a period of time during which they will exhibit their influence. It is this evolution of the system in time that is its primary characteristic, not its state at any instant.

2. The behavior of a system is ultimately controlled by its structure, that is by the combination of Stocks and Flows of which it is composed and by the positive and negative feedback loops that control the Flows.

3. Systems are defined by their Stocks and Flows (or by their Accumulations and Rates). Your personal financial system, for example, is defined by a variety of Stocks of money (what's in your wallet, in your checking account, in the National Treasury, etc.) and the Flows that transport money between those Stocks (interest payments into your savings account, tax payments to the IRS, your paycheck moving money from your employer to you, etc.).

4. Controls of systems are circular feedback relationships, not linear chains of cause and effect. Looking at systems means abandoning those simplistic, linear, one-way chains of cause and effect that lead to a final answer, such as:

A ===> B ===> C ===> D

Systems Thinking teaches that the most interesting causal relationships are, in fact, circular, in that A influences B which influences C which in turn influences the original A again which ...

5. These causal loops (or feedback loops) come in two basic "flavors." Positive feedback loops (perhaps better called "reinforcing" loops) are those where, if you "push" factor A in one direction, it leads to a cycle (causal loop) of subsequent activity that eventually results in A being pushed further in the original direction. A common example is a biological population: A population of organisms grows as new individuals are born into it; with more individuals now in the population, even more are born into it; which further increases the size of the population; which increases the flow of new individuals; etc.

Negative (or "stabilizing") feedback loops are quite different. Push A in one direction and you set in motion a sequence of events that ultimately leads to A being pulled back toward the position where it started. A simple example: As you fast after your last meal or snack, your hunger increases. This eventually sets in motion events that result in your eating, which reduces your hunger. Hunger began by increasing, but the course of events ended by your hunger being reduced back to its original low level.

Dynamic Modeling

Dynamic Modeling provides a means to rationally, objectively, and precisely wrap our minds around systems. Even "simple" systems with relatively few seemingly straightforward components can present complexities, as they evolve in time, that are beyond our brains' abilities to decipher. Modeling — and here we mean not just computer simulation modeling but a variety of very powerful and useful mental and graphical modeling approaches that provides a means to define the structure and behavior of a given system and to project that structure and behavior into the future. Such modeling can serve a number of purposes. Our focus with a given type of model depends on the specific scenario and our particular needs:

1. Models provide a common and objective language for diverse individuals to discuss a particular issue. "Raising taxes is stupid!" may be a genuine and heart-felt belief, but it is very hard to come to grips with a statement like that. Oblige that discussion to be framed within the context of a stock/flow diagram, causal loop diagram, or computer model, however, and you are quickly forced to recognize that taxes represent a Flow of money from one Stock to another Stock, and that as those Stocks rise and fall as a result, there are implications on other components of the system. Whether those implications represent improvements or worsenings in your situation or that of your town, state, or nation now can be more objectively discussed.

2. Construction of a model obliges us to be very clear and precise in defining which component influences which and in what manner that influence is wielded. Does an increase in government revenue alter the way in which government spends that money? Is it likely to spend its "windfall" foolishly or inefficiently, or will it spend it in a manner that will increase the common good? We probably have a "mental model" of that; building and communicating that model forces us to explicitly and clearly define that mental model.

3. Construction and communication of a model provides a powerful framework for collaboration between diverse stakeholders in the system in question. Can we identify areas of agreement? Can we clarify and better understand areas of disagreement? Can we resolve the latter?

4. Construction of a model often reveals areas of ignorance where new information must be gathered or discovered through original research. From a previous point: If there is a disagreement on the likely effect of new revenues on government spending, can or should we explore what has historically been the effect of such changes in other similar instances?

5. Precise computer models allow you to play "what if?" games and explore the implications of specific courses of action,i.e., "policies." Does a tiny change in one component lead to massive changes in the system's behavior? Does a huge change in another component have negligible effect? This "sensitivity analysis" provides a powerful means to determine where we might get the "most bang for the buck" by identifying the high leverage points where a small manipulation leads to large improvements.

Similarly, a model allows us to test the result of a policy decision before implementing it. By compressing time, we might simulate 100 years of environmental dynamics in seconds. Better to have the computer suggest the danger of continued ozone release than to perform the global experiment and suffer the consequences for several generations!

Modeling Tools

1. Knowledge: Knowing (or perhaps agreeing on) the behavior of the system is the first, and often quite challenging, step in our analytical process. Here a particularly useful visual modeling tool is construction of a "Behavior Over Time Graph" (or "Reference Mode") that plots the dynamic changes of the system over time. As well, what is the likely, or desired, or feared behavior of the system as we project it into the future? Hand in hand with use of Behavior Over Time Graphs, on this rung of the Ladder we frequently begin to develop a basic definition of the dynamics that lead to such behavior. A simple "Stock-Flow Map" can be developed to define the stock of interest and identify the flows that contribute to or drain from that stock.

2. Understanding: Given a dynamic behavior, what in the system controls it? A basic tenet of SD is that feedback loops are fundamentally important in understanding why a system does what it does. Identifying and understanding those feedbacks is necessary before effective intervention in the system will be possible. Two tools useful for that purpose are "Causal-Loop Diagrams" and "Stock-Flow Maps."

3. Influence: Here, the objectivity of "Computer Simulation Models" becomes critical. Being able to intuit the interaction of multiple, often non-linear feedback relationships is simply beyond our unaided mental ability. Are our mental models complete? Accurate? Do they result in unanticipated consequences? Undesired consequences? These are the pitfalls that computer modeling can help to avoid.

Creating a System Dynamics Model

System dynamics adheres to viewpoints and practices that set it apart from other fields dealing with the behavior of systems (Randers, 1980). System dynamics is distinguished not only by the particular cluster of beliefs that guide the work but also by the degree to which those characteristics are indeed practiced. The model boundary is to be established so that the causal mechanisms lie inside the boundary. This expectation of finding endogenous causes of behavior is in sharp contrast to the view often found elsewhere (Richardson, 1991). People are far more comfortable blaming their troubles on uncontrollable external causes rather than looking to their own policies as the central cause. Business managers attribute product and corporate failures to competitors, bankers, and government rather than to their own handling of resource allocations, pricing, and interpretation of customer needs. Governments blame balance of trade difficulties on other countries rather than recognizing the cause in domestic deficits, tax policies, and monetary actions.

The system dynamics emphasizes on endogenous behavior. System dynamics models build from the inside to determine and to modify the processes that cause desirable and undesirable behavior.

Effectiveness of a model depends on how it uses the wide range of information arising from the system being represented (Forrester, 1980). In creating a system dynamics model, information is used in a substantially different way from that in other branches of the social sciences. The differences arise from the system dynamics focus on policy statements as the basic building blocks of a model and from a broader range of information sources used for creating a model.

Information is available from many sources. Figure 5, suggests three classifications of information — the mental database, the written database, and the numerical database. Although "data" is a term that is often used to mean only numerical information, the dictionary meaning is far broader. Data is "something that is given from being experientially encountered" and "material serving as a basis for discussion, inference, or determination of policy" and "detailed information of any kind" (Webster's Third, Unabridged).

Decreasing Information Content

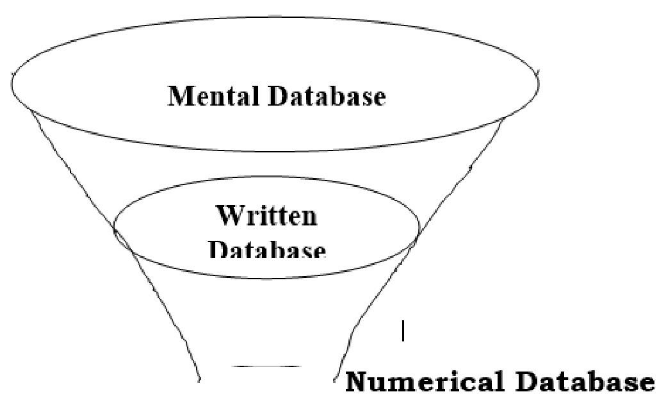

Figure 5: Decreasing Information Content

The mental database contains vastly more information than the written database, which, in turn, contains far more information than the numerical database. Furthermore, the character of the information differs in the three categories. As one moves down the diagram, each category of information contains a smaller fraction devoted to structure and to description of policies. That is, the written and numerical databases contain not only less information but also progressively smaller proportions of the information needed for constructing a dynamic model.

If the mental database is so important to the conduct of human systems, then a model of such a system should include relevant knowledge from all available sources, including that which resides only in the mental database. The mental data base is rich in structural detail; in it is knowledge of what information is available at various decision-making points, where people and goods move, and what decisions are made. The mental data base is especially concerned with policy, that is, why people respond as they do, what each decision-making center is trying to accomplish, what are the perceived penalties and rewards, and where self-interest clashes with institutional objectives.

With regard to the use of data, system dynamics operates more like the engineering and medical professions, and less like practices in economics. All information is admissible to the process of model building. Information from the mental database is recognized as a rich source of knowledge about structure and the policies governing decisions. Parameter values are drawn from all available sources, not merely from statistical analysis of time series. The mental and written databases are the only sources of information about limiting conditions that have not occurred in practice but which are important in determining the nonlinear relationships that govern even normal behavior.

An Example

Like any other model, a SD model is also a representation of the real life system which can be used to study the system behaviour under different test conditions. It utilises all the three modes of communication in preparing the representation of the system, i.e., words, graphics and mathematics. It follows the logical sequence of the use of these three models as the clerity about the system structure in developing in different stages which is shown in Figure 4.

Modes of Communication and Representation of Real Life

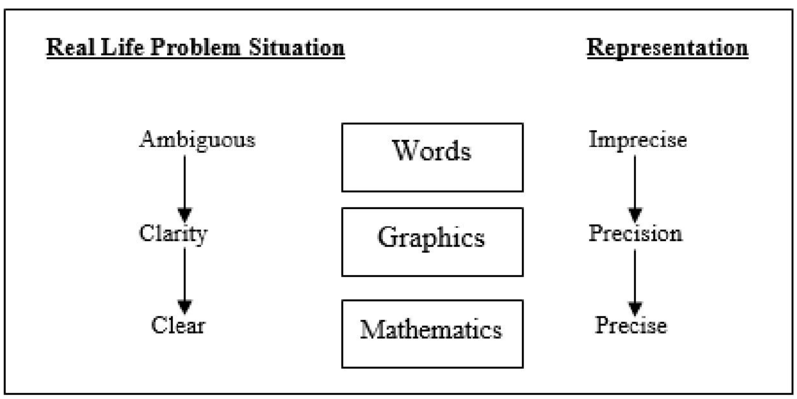

Figure 4: Modes of Communication and Representation of Real Life

Such a representation of the system can be simulated on a computer to study its behaviour and can be manipulated by changing the policies to give the desired or improved behaviour.

In tune with the defination of the SD model given in the first section, an example model of a practical situation is presented here, which follows the same logic sequence, i.e., words, graphics and mathematics in the following three stages: (i) Problem situation; (ii) Diagrametic representation; (iii) Equations.

After the presentation of the model, its simulated behaviour under test conditions is discussed. The model presented here deals with describing conditions in a Standardisation, Testing and Quality Control Programme to suggest improvement in policies for its better performance.

Problem Situation

Suppose the Standardisation, Testing and Quality Control (STQC) Programme was set up by the Department of Electronics to provide standerdisation and certification support at National and International level as well as to render testing, calibration, consultancy and related services to the electronic industry.

The STQC services are rendered through a national network of 21 laboratories established in a two tier formation at the industrial centres.

The number of services of the STQC are effected by the customer satisfaction and the quality awareness. It is also observed that the quality of the service can be improved by increasing the competence of engineers. The engineers competence can be increased by training.

The number of engineers/technicians determine the amount of work, i.e., number of jobs that could be performed. Therefore, hiring of the personnel is related to the number of people associated for accomplishment of average type of job. The newly joined people cannot start work at their full efficiency that certainly takes some time to adjust. The hiring of the people is also dependent symultaneously on the average number of people leave STQC or the average duration of their stay at STQC.

For the purpose of modeling only the simple relationas are considered. Initially there are 10 engineers/ technicians. It is also considered that the newly joined people take approximately 12 months to settle down and start work at the capabilities required. One engineer, on an average, can perform two jobs. It is also recorded that an engineer stays with the STQC for near 10 years of his/her career. At the time STQC performs 1000 jobs per year with the manpower capability of marketing of the job of the order of 2 units per year per person. However, there is a regular increase in the service request for service at the rate of 10% per year. At present the finances available with the company are Rs. 10 lakhs, whereas the average test charges for a single unit is Rs. 9000. The total outlay for the expenditure towards salary of the people and other contingencies is Rs. 50,000 per person.

Diagrametic Representation

Causal Loop Diagram: The causal loop diagram portray the cause and effect relationships between various variables in the problem situation. These relationships which are portrayed in the form of causal links can be identified and justified in many ways. Coyle (1977), Richardson and Pugh (1981) and Kim (1992) had given some guidelines to prepare a causal loop diagram. The important variables and linkages in the problem situation are identified and the causal loop diagram is developed as shown in Figure 6. This dipicts two positive feedback loops and two negative feedback loops.

Flow Diagram: The flow diagram is usally treated as the ultimate diagrammatic representation that aids the writing of equations. The flow diagrams are to be either developed from the causal loop diagram or the policy structure diagram, or both, or directly from the policy statement. The first step in developing the flow diagram should be to define the levels. Once the levels are defined, then we can draw them one-by-one using the box symbol.

Equations

The causal loop diagram is converted into the flow diagram by defining the level and rate variables. For our example, three important levels could be defined as manpower, services and finance. The equations for the flow diagram can be written in a DYNAMO framwork. DYNAMO is a software package for solving the SD model.

Some of the other currently available software packages to support the SD modeling are DYSMAP (Dynamic System Modeling And Analysis Package, developed by Ratnatunga, 1975), STELLA (Systems Thinking Experimental Learning Laboratory with Animationdeveloped by Richmond, B.Peterson, S. and Vescuso, P., 1987), DYBASE (Dynamic Simulation with Data Base, Narayana and Sushil, 1991), DYMOSIM (developed by Bora and Mohapatra, 1985) and DYNER (developed by

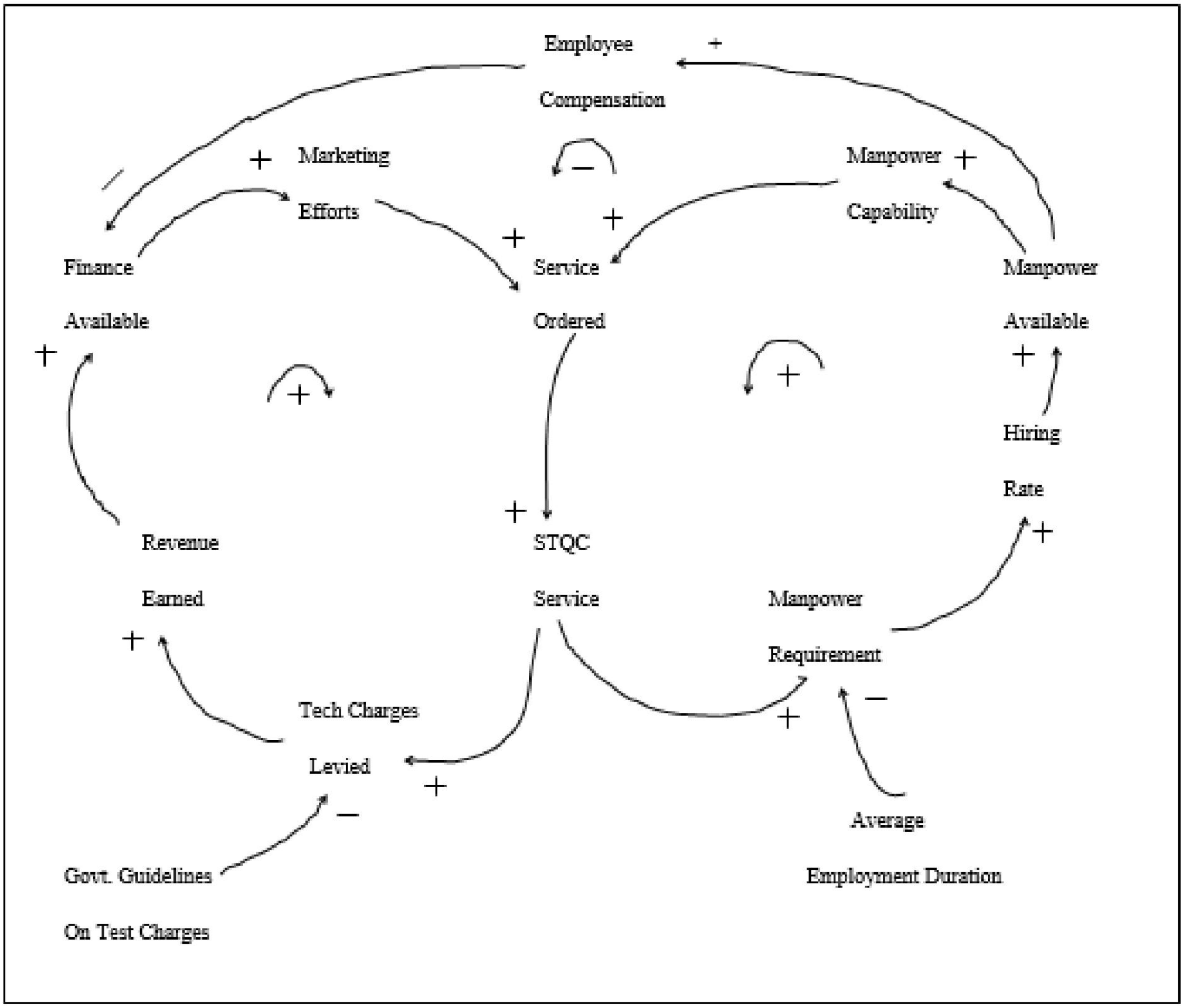

Figure 6: Causal Loop Diagram of the STQC Model

Systems Research Institute, Pune). The equations are written in the same order as that of the flow diagram, i.e., first a level equation, then the equation of associated rate followed by its policy structure, and then next rate and its policy structure

The field of System Dynamics (SD) was founded by Dr. Jay Forrester at MIT in the 1950's. Historically based on feedback systems in mechanical and electrical engineering systems, SD builds on several realities that are generic to all dynamic systems. These can, in broad terms, be divided into three broad and interrelated categories: Systems Thinking (ST), Dynamic Modeling (DM) and Modeling Tools:

Brief Review of Past Applications in Corporate Managerial Applications

The very first application by Forrester (1958) in the area of advetising in a production distribution system and subsequently the work "Industrial Dynamics" (Forrester, 1961) is the successful example of SD modeling at the corporate level. These deal with the advertising policy, distribution policy, inventory policy and the ordering policy at various levels.

Justification of Using SD for Managerial Problems

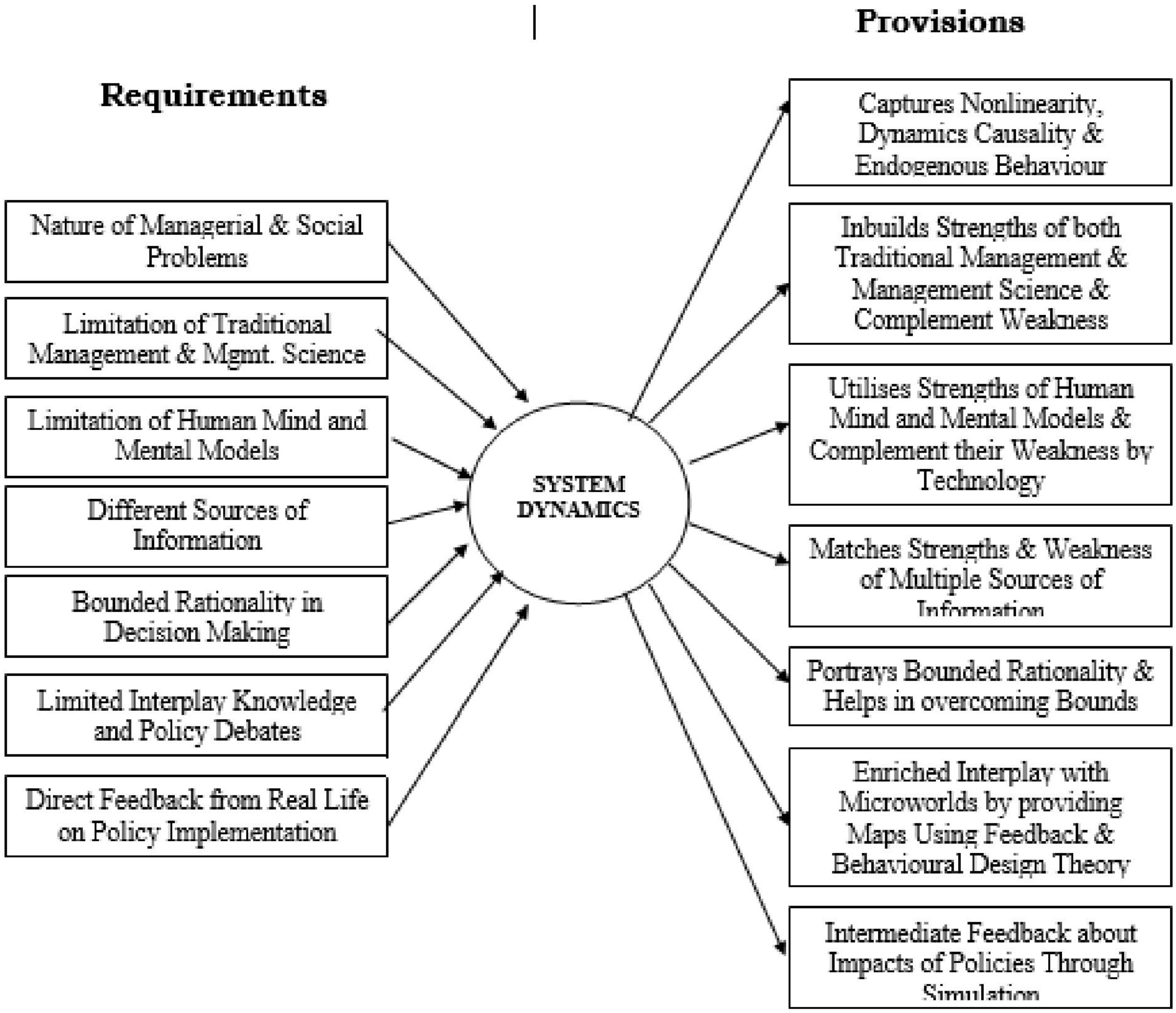

Figure 7: Justification of Using SD for Managerial Problems

Some sample studies covering applications in different areas mentioned above are succinctly reviewed here in a chronological order.

- Griffin (1977) demonstrate causal modeling for the study of psychological success in work organizations.
- Thietart (1977) tried to understand human behaviour and more precisely human performance in an organization using SD methodology.
- Shehata (1977) tried to explore the applicability of the SD methodology to the formulation of long range cash flow policies.
- Roberts (1978) reported managerial applications of SD
- Lynesis (1980) provides an extensive application of SD to corporate planning and policy design.
- Fischer and Mclanghlin (1980) examine a SD simulation of management by objectives (MBO) in a research and development setting.

- Craig (1980) describes a methodology for constructing financial planning models using computer package developed by the author, i.e., GENSIM (an acronym for Generalised Simulation System). The GENSIM package is based on the concept of both SD and input analysis, and is designed to provide general management with a flexible and easy to use modeling facility capable of supporting the development of dynamic simulation models of both financial and non financial systems.
- Kleiner and Kumar (1982) demonstrated the application of SD for corporate planning.
- Kumar (1984) developed a modular approach for production systems based on the SD methodology.
- Sohn and Surkis (1985) have presented the use of SD as a methodology for modeling and testing dynamic behavioural hypothesis in organisational behavioural studies.
- Moffatt (1986) reported a dynamic model of environmental conflict and structural change.
- Narchal (1988) reported a simulation model for corporate planning for a steel plant on SD principles which is being used by the management for simulating the impact of their strategic policy decisions on corporate objectives, and also assists the management in designing their long range investment policies related to expansion, modernization and the smooth flow of production.
- Keats and Hilt (1988) demonstrated a causal model of linkages among environmental dimensions, micro organisational characteristics and performance.
- Pankaj, Sushil and Seth (1990) and Pankaj, Sushil and Seth (1992) demonstrated the use of SD for designing Expert Support Systems along with Fuzzy Set Theory.
- A SD model to study group dynamics is developed by John and Sushil (1991)
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System Dynamics in Business Management

The range of managerial problems in any organization is very vast, ranging from simple to complex; from well structured to unstructured; from hard to soft; from quantitative to qualitative; from short time horizon to long time horizon; from operational to strategic; from single person to whole organization; etc. SD being a simulation methodology can be used to model a wide range of managerial problems. However, the use of SD is more effective in some cases than others, and the effectiveness of application depends largely upon matching the problem characteristics with the characteristics or feature of the methodology.

Forrester (1998) mentions four business areas in which system dynamics can address business problems:

Several powerful examples of generic models already exist:

- Stability and fluctuation in distribution systems,
- Pricing and capital investment as they determine growth,
- Promotion chains showing evolution into a top-heavy distribution of management personnel when growth slows,
- Imbalances between design, production, marketing, and service as they influence market share.

Each such model manifests many modes of behavior ranging from troublesome to successful depending on the policies employed within it. These models can be modified and adapted to address specific company problems in these areas.

According to John Sterman, system dynamics may be an appropriate methodology for addressing various business problems in any of the following listed areas:

- Evaluating response to industry or competitor innovations
- Improving large project management
- Understanding the complex relationship between equipment maintenance and business results
- Innovation diffusion, including the spread of of new ideas and market growth of new products.
- The development of positive feedbacks that can cause a firm or industry to grow or decline, including, product awareness, unit development costs, price and production cost, network and complementary good effects, product differentiation, new product development, market power, mergers and acquisitions, workforce quality and loyalty, cost of capital, organization size and success, and ambition and aspirations.
- Achieving desired demographics in organizations, such as number of people in various job categories, skills, age, race, gender, etc.
- Price setting in commodity industries and stock markets
- Optimizing the mix of inputs to a production process
- Handling increasing backlogs of work with existing capacity, in both manufacturing and service industries
- Improving product development performance - reducing time to market
- Improving ability to grow market share
- Improving forecasts while reducing forecasting costs
- Improving management of inventories and supply chains, not only in manufacturing industries, but also in industries such as real estate.
- Reducing inventory/workforce oscillations
- Better understanding your industry's business cycle, thus improving your organization's ability to deal with the cycle.
- Understand, and thereby design policies to enable your organization to better deal with your industry's supply, demand, inventory, and price cycles.

Top Management Problems/ Issues for SD Applications

The top managers are primarily responsible for policy making and strategic planning. The SD methodology is helpful in different phases of strategic planning and it can be effectively used for developing corporate planes and can aid in examining the issues like modernization, diversification, acquisitions/mergers, sickness, etc. A representative list of top management problems that can be aided by SD modeling is given below:

Sl. No.	Top Managerial Problems
1.	Goal Setting
2.	Strategy Formulation
3.	Policy Planning
4.	Corporate Planning
5.	Modernisation
6.	Investment Policy
7.	Diversification
8.	Acquisition / Mergers
9.	Corporate Sickness
10.	Portfolio Planning
11.	Impact of Government policies
12.	Scenario Building
13.	Managing Competitive Environment
14.	Management by Objectives (MBO)
15.	SWOT Analysis

Middle Management Problems/Issues for SD Applications

The role of middle management is more of control and coordination of organisational activities. As the middle manager has to deal both with the top and the first line managers, they have to be conversant with the strategic as well as operational planning. The SD model acts as a vehicle of integration in the organization by making the managers to learn and appreciate the problems of other functional areas through a formal approach. A selective list of the middle management problems that can be aided by SD modeling is given below:

Sl. No.	Managerial Problems/Issues
1.	Marketing Policy
2.	Advetising Policy
3.	Distribution Policy
4.	Financing/Borrowing Policies
5.	Medium Term Investment Policy
6.	Manufacturing Policy
7.	Inventory Policy
8.	Productivity Planning
9.	Human Resource Policy
10.	Recruitment Policy

11.	Training Policy
12.	Employee Promotion Policy
13.	Employment Instbility
14.	Production Fluctuations
15.	Declining Profitability
16.	Control of Delays
17.	Organisational Analysis and Design
18.	Analysis and Design of MIS/DSS

Operational Management Problems/Issues for SD Applications

As the first line or operational managers are more involved with the implementation of policies, the relevance of SD applications is reduced. The SD methodology can be used more to provide microworlds and learning environment to the operational level managers so that their understanding about the system functioning improves. This can be utilized both for better implementation of policies and for more realistic use of other normative models for decision-making. A short list of important operational management problems, which can find SD methodology applicable, is given below:

Sl. No.	Managerial Problems/Issues
1.	Demand Estimation
2.	Production Planning
3.	Loading and Scheduling
4.	Materials Planning
5.	Quality Planning and Control
6.	Orders Clearing
7.	Order Placement

Functional Management Problems

The SD methodology has found application in all the functional areas of management. The functional management policies are integrated by the SD methodology by the corporate models. The problems in different functional areas, amenable to the SD modeling, are summarised in Table 1.

What We Can Learn?

The SD methodology has been applied in past at macro-economic level; Sectoral level, e.g., energy, transport, minerals, oil, power, environment, forecast, agriculture etc; generic industry level, e.g., steel, aluminum, tea, paper, etc; and at the corporate firm level. The SD applications are more suitable to managerial problems, which are at the policy level, loosely structured, qualitative and complex. The applications of SD are very much suitable to top management problems, such as strategy formulation, policy planning, corporate planning, modernization, diversification, portfolio planning, competitive environment, etc.

The SD methodology has also found wide application at the middle management level. Various problem areas that can be addressed to SD applications are marketing, distribution and advertising policy; financial policy; manufacturing and inventory policy; human resource policy; employment instability, design of MIS/DSS etc.

Table 1: Functional Management Problems for SD Applications

Functional Area	Managerial Problems
Marketing Management	New Product Diffusion Pricing Advertising Distribution
Financial Management	Financing Investment Dividend Capacity
Operations Management	Product Planning Process Planning Productivity Planning Quality Planning Aggregate Production Planning Materials Planning
Human Resource Planning	Recruitment Selection Training Development Appraosal Group Dynamics Organisational Behaviour

At the operational level, though the application of SD can be made successfully in areas such as production and materials planning, order placement and clearing, etc., it is not much advisable to use SD in many operational level problems as there are more structured techniques that can cater to the operational level problems more successfully.

SD is applicable to managerial problems in all functional areas such as human resource management, marketing management, financial management, operations management, strategic management, systems management and operations management.

There is a growing trend to use SD models for organization design, MIS, DSS, Expert Support System, uncertainty management or risk management, supply chain management, asset liability management, total quality management and knowledge management.

Thus we have seen a large number of studies have been reported on SD applications at the corporate level, and in different functional areas. Here, it may be noted that the SD application in a functional area means that managerial problem to be modeled primarily lies in that functional area. But the SD structure model to represent this, usually, cut across the boundaries of the functional areas. For example, an inventory problem in the operations management might involve manpower policy and financial implications. The SD philosophy is based on representing the structure in terms of underlying flows cutting across the barriers of different functional areas.

The major strength of SD is its flexibility to meet different requirements of various problem situations. It's starting point is manager's experience and thus the approach is more practical and can be easily adopted by the managers in a participative manner. The major limitation of SD is, that if the managers are having strong biases, the models may be biased. The flexibility of the approach requires more skills on the part of the managers to effectively use this methodology.

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