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Industrial Dynamics to Systems Thinking

A.K.Rao & A. Subash Babu *

ABSTRACT

Prof. Jay W. Forrester pioneered industrial Dynamics. It enabled the management scientists to understand well enough the dynamics of change in economics/business systems. Four basic foundations on which System Dynamics rest were discussed. The thought process prevailing and their shortcomings are pointed out and the success story of System Dynamics was explained with the help of Production-Distribution model. System Dynamics graduated to Learning Organisations. Senge with his concept of integrating five distinct disciplines of Systems Thinking, Personal Mastery, Mental Models, Shared Vision and Team Learning succeeded in bringing forth the System Dynamics to the reach of large number of practitioners and teachers of management. However, Systems Thinking part of the Learning Organisation fails to reach out because it lacks the architecture needed to support it. Richmond provided the much-needed architectural support. It enables the mapping language to be economical, consistent and relate to the dynamic behaviour of the system. Progression from Industrial Dynamics to Systems Thinking has been slow due to different postures taken by the professionals. It is suggested that Systems Thinking has a lot to adopt from different disciplines and should celebrate synergies and avail cross-fertilisation or opportunities. Systems Thinking is transparent and can seamlessly leverage the way the business is performed.

* A. K. Rao is Member of Faculty at Administrative Staff College of India, Bellavista, Hyderabad 500 082, India. E-mail: akrao@ascihyd.org and A.Subash Babu is Professor in Industrial Engineering and Operations Research at Indian Institute of Technology, Bombay 400 076, India E-mail: subash@me.iitb.ernet.in

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Introduction:

In the year 1958, the first words penned down by the pioneer of System Dynamics (then Industrial Dynamics) Jay W. Forrester were "Management is on the verge of a major breakthrough in understanding how industrial company success depends on the interaction between the flows of information, materials, manpower and capital equipment". The article titled "*Industrial Dynamics: A Major Breakthrough for Decision Makers*" in Harvard Business Review attracted attention of management scientists. Several controversies arose when further articles appeared subsequently.

Today, 40 years since the first article in the field of System Dynamics appeared in print, the progress when evaluated evokes mixed response. If it were a major breakthrough for decision-makers, then why did it not proliferate into the curriculum of business schools as common as that of Principles of Management or Business Statistics or any other standard subjects of study? The purpose of this article is to critically review three seminal works in the field of System Dynamics: Industrial Dynamics by Jay W. Forrester (1960), Fifth Discipline: The Art and Practice of Learning Organisations by Peter Senge (1990) and Systems Thinking by Barry Richmond (1997) and to understand the pitfalls in reaching out to the large body of academia and practising managers. Forrester in his work raised a few fundamental issues way back in early 60's that most of the corporate managers are able to comprehend only now. He clearly answered the question on what is the next frontier of our knowledge. The great advances and opportunities in the future he predicted would appear in the field of management and economics. The shift from technical to the social front was evidenced in the way global competition and the rules of the game changed. The test of leadership is to show the way to economic development and stability. The leading question therefore is whether we understand well enough the dynamics of change in economic/business systems to pioneer this new frontier?

Forrester offered the much-needed solution: System Dynamics. The foundations for a body of knowledge called system dynamics were the concepts of servomechanism, controlled experiments, and digital computing and better understanding of control theory. Servomechanism of information feedback theory was evolved during the World War II. Till then, time delays, amplification effects and the structure of the system were taken for granted. The realisation that interaction between components is more crucial to the system behaviour than the components themselves are of recent origin. The thesis out of information-feedback study led to the conclusion that information-feedback system is all pervasive in the nature. It exists whenever the environment changes, and leads to a decision that results in action, which in-turn affects the environment. This leads us to an axiom that everything that we do as an individual, as an organisation, as an industry, as a nation, or even as a society irrespective of the divisibility of the unit is done in the context of information-feedback system. This is the bedrock philosophy of system dynamics.

The second foundation is the realisation of the importance of the experimental approach to understanding of system dynamics. The standard acceptable format of research study of going from general analytical solution to the particular special case was reversed to the empirical approach. In this format a number of particular situations were studied and from these generalisations were inferred. This is the basis for learning. The activity basis for learning is experience. Some of these generalisations were given a name by Senge (1990) as Nature's Templates.

The third foundation for progress of system dynamics was digital computing machines. By 1945, systems of twenty variables were difficult to handle. By 1955, the digital computer appeared, opening the way to the simulation of systems far beyond the capability of analogue machines. Models of 2000 and more variables with out any restrictions on representing non-linear phenomena could easily be simulated on a digital computer at costs within the reach of the academia and the research organisations. The simulation of information feedback models of important managerial and economic questions is an area demanding high efficiency. A cost reduction factor of ten thousand or more in computation infrastructure placed one in a completely different environment than that existed a few years ago.

The fourth foundation was better appreciation of policy and decision. There is an orderly basis that prescribes most of our present managerial decisions. These decisions are not entirely adhoc but are strongly conditioned by the environment. This being so, policies governing decisions can be laid down and their effect on economic/business behaviour can be studied.

Forrester's Postulates and Applications:

The idea that economic and industrial systems could be depicted through linear analysis was the major stumbling block to begin thinking dynamically. Most of the policy analysis goes on to define the problem on hand as narrowly as possible in the name of attaining the objective of being specific and crisp. On one hand, it enables the mathematics of such analysis tractable but unfortunately, it ignores the fact that almost every factor in the economic or industrial systems is non-linear. Much of the important behaviour of the system is the direct manifestation of non-linear characteristic of the system components.

Social systems are assumed to be inherently stable and that they constantly seek to achieve the equilibrium status. While it is the system's tendency to reach the equilibrium in its inanimate consideration, the players in the system keep working towards disturbing the equilibrium conditions. Perfect market is the stated goal of the simple economic system with its most important components the supply and the demand trying to equal each other in the long run. But during this period, the players in the market disturb the initial conditions by several means such as inducing technology, introducing substitutes, differentiating the products etc. which makes that the seemingly achievable perfect market an impossible dream. Therefore, the notion of sustainable competitive advantage is only fleeting in nature. The analysis used for solving the market problems with an assumption of stable systems in thus not valid. There appears ample evidence that much of our industrial and economic systems exhibit behaviours characterised by instability.

Mathematical economics and management science have often been more closely allied to formal mathematics than to economics or management. The difference of orientation is glaringly evident on comparison of business literature with publications on management science. Another evidence of the bias towards mathematical rather than managerial motivation is seen in preoccupation in optimum solutions. In the linear analysis, the first action that is performed is to define the objective function. Thus specifying the purpose of a model of an economic system being its ability to predict specific future action. Further, it is used to validate the model. Models are required to predict the character and the nature of the system in question so that redesign could take place in congruence with the desired state. This is entirely different and more useful than the objective functions, which provide the events such as specific future times of peaks or valleys such as in a sales curve.

It is a belief that a model must be limited to considering those variables, which have generally accepted definitions and must have objective value, attached to them. Many undefined concepts are known to be of crucial importance to business systems, which are known as soft variables. Linear models are not capable of capturing these details in the traditional methodology of problem solving. If the subjective matters are considered to be of crucial importance to the business system behaviour, it must be conceded that they must some how be incorporated in the model. Therefore, it is necessary to provide legitimate definitions for those variables.

Often, it is argued that data collection must precede the model construction. Given this constraint, it becomes necessary that the model be restrained to those variables for which numerical time series data exists. A model of system behaviour must consider those variables that are thought to control the system action. If data does not exist in the files, best guesses must be substituted till actual measurements are taken. The best guesses can be made only with an insight in to the system and it is generally available through descriptive knowledge.

In the academic circles, it is believed with contempt that the managers rely on descriptive knowledge. The business managers' method is descriptive knowledge and his skills are measured by his acuteness in perceiving the motivations and interrelationships in economic and managerial affairs while it has become the preoccupation of the academicians to include those searching problems to fit into available mathematical tools. Therefore, the model building being the domain of the academician, it is considered that our vast body of descriptive knowledge unsuitable for use in the model formulation. Formal numerical data has been the preferred component for model building to that of the best guesses culled out of the vast wealth of information containing in the business press. It is a common knowledge whether business decisions are made on the basis of formal models of the academia or the business press that publishes perceptive insights into the reasons for managers' decisions.

A conspicuous gulf exists between the practising managers and the academicians because both the communities strongly believe that there is a sharp distinction between the exact and the social sciences. Forrester argued that exactness and accuracy must not be measured in terms of decimal places but in terms of requirements. The design and construction of a microchip may require measurements significant to sub-micron levels. The next advancement is based on the preceding level of accuracy. In other words, exactness is related with numbers and the social sciences deal with insights through logical arguments. Senge (1990) warns that if you wanted to design a cave person for survival, ability to contemplate the cosmos would not be high-ranking design criterion. What is important is the ability of the person to see the sabre-toothed tiger over his shoulder and react quickly. Dramatic progress is possible in the dynamic behaviour of the systems using parameters that may not even be correct in the first decimal place.

Physical systems or genetic science are construed as proper analogy for model building in the social sciences. Physical systems and genetic sciences relate to fragments of systems rather than entire systems. Further, they are open systems rather than information-feedback systems. For instance, genetics determine future generation while the present generation has no chance to effect the previous one. A much better analogy exists in engineering systems such as ballistic systems or even the simple limit switches that control movement of the tables of a machine tool.

A great deal of time and effort are expended in social studies in the measurements of parameters with a belief that accuracy of parameters is of greater importance than the structure of the system. Parameters, however correct can hardly succeed in a grossly incorrect model structure. Failure to capture the required system structure and their information feedback loops, motivates the model builder to adopt the existing parameters with their data adequacy, with their accepted definitions to fit into an existing paradigm of producing optimum solutions with an extremely local perspective.

Systems management can prove to be tremendously gainful. Mere improvements will be dramatic even when it falls short of some optimum. The obsession of the mathematical economist to find optimum solutions might satisfy the elegance of the model in its mathematical rigour but of little value for putting it into practice. An example of such gain is evident from the history of inventory control systems. Order point system to control inventory dominated till 70's. In Materials Requirement Planning (MRP) a concept propounded by Orlicky, an attempt is made to develop a more realistic model of a particular situation. However, the trade-off for additional realism is often accompanied by the absence of a clearly defined optimisation. Sometimes, there may not even be a mathematically stated objective function. The model strives to find a feasible solution that is hoped to provide a reasonable performance. This is the philosophy underlying the MRP. Several organisations that were not using any scientific inventory control methods earlier quickly adopted MRP concept. The major difference is that order point systems were mathematically rigorous and the user seldom had the mastery over it. While MRP system is essentially less analytical and due to its common sense approach, it was more germane to the understanding of the user and therefore the immediate acceptance followed. At the same time, it had no explicit objective function nor any constraints specified under which some objective to be optimised. It was simply a statement of logical progression and dramatic improvements accrued to those who adopted it. Therefore, the lesson to be drawn from the experience is that more is to be gained by improving areas of major importance than by optimising areas of minor importance.

System Dynamics has been dubbed by some as the new dismal science because it shows that most obvious solutions do not work and to make things worse, they improve matters in the short run only to make things worse in the long run. Quick fixes are adopted for gaining in the short run by mortgaging the future. This tendency to believe that System Dynamics is the new dismal science stems from the belief that human decision making is the most obscurely subtle and impenetrable. System Dynamics also shows that small, well-focused actions can sometimes produce significant and enduring improvements when they are placed right. This is so because, the human decisions though seem impenetrable at the outset, major factors to which a decision is responsive are relatively small in number. This is termed as leverage in System Dynamics parlance.

Policy and decision making are thoroughly confused and sometimes used synonymously. The result is managers task is obscured. Policies are those rules by which input information streams are converted into decisions to control activity. The decisions are the continuously generated results of applying the policy to the input data flows. With the prevailing confusion on policy and decision making, organisations are sharply divided by strong departmentalised structure. This type of structure inhibits inquiry across boundaries. Standard turf wars one comes across in the organisations are due to the rigid boundaries thus created. Living systems have integrity because nature integrates and never differentiates. Their character depends on the whole. Therefore, the challenge to the managers is to see the whole system that generates the behaviour.

Success Stories:

Forrester in his book likened Industrial Dynamics models in their purpose and origin to models of engineering than to models in the physical, genetic or agricultural sciences. Industrial dynamics models are closed loop information feed back systems, not models of open ended systems in which results do not react on causes. He argued convincingly that mathematical models make controlled experiments possible and allow us to see the effect of the separate parts of the system. A management laboratory then becomes possible for the design of improved managerial policies. The dynamic model thus serves as a tool for the design of policy and organisational form.

Forrester discussed at length dynamic model formulation. The rules he prescribed to formulate a dynamic model are that the models must be simple that still retain the essence of the system. Dynamic models must have closed loop structure that gives rise to dynamic behaviour of interest since all economic and industrial activities are closed loop information feedback systems. The essential characteristics of information feedback systems arise from organisation structure, policy, amplification and delays and therefore, a dynamic model should represent these. A dynamic model should be constructed to correspond to the features and policies of the actual system. Dynamic systems should be formulated in the continuous form. Periodic review of decisions can be done after the fundamentals of the continuous system are understood. That it can not be assumed that the systems will be linear or stable.

The system dynamics concepts were discussed with the help of a simple production-distribution system in the book. The structure was found to correspondence to the important dynamic characteristics of managerial activity. The model consists of an alternating system of levels and flows. The flow channels transport the contents of one level to another, and the levels control the flow rates themselves. The decision functions are the relationships that describe how the levels control the flow rates. Information channels connect the levels to the decision functions. The system considered in his book is given in Fig.1.

The production-distribution system was used to show how the structure and the policies of an organisation could give rise to undesirable modes of behaviour. The sample provides insights as to how small changes in retail sales can lead to large swings in factory production, which is referred as Forrester's Effect in supply chain management context. Other significant results demonstrated through this model were; how reducing clerical delays may fail to improve management decisions significantly, how a factory manger may find himself unable to fill orders although at all times he is able to produce more goods than they are sold. How an advertising policy can have a magnifying effect on production variations. Digital computing simulation was used to obtain answers to the above questions. DYNAMO compiler was used to generate code for simulating the model.

If the information-feedback system were all pervasive, and the basis for learning was experience, then why did they escape notice till Forrester came up with System Dynamics? The reason is that we took several systems for granted. Examples such as human body's homeostatic state, neuro muscular co-ordination, rainfall etc were existing. We took them for granted because they were perfected so ideally for their purpose and their characteristic of information feedback escaped attention. On the other hand, social/business systems are of recent origin and are so large in scale and complex in nature in comparison with simple systems as cited above, the fundamental characteristic of information feedback was difficult to discern. Engineering however mastered in capturing the feedback characteristics of some of the complex systems. But the mathematics was unable to cope with the problems of major engineering challenge. Engineers therefore, didn't wait for analytical solutions but adopted linear and non-linear mathematical models. These models were constructed and solutions were found with the help of analog computing machines. Social systems/business systems are much more complex than those systems already mastered in engineering. The question then was how should one tackle these problems? Forrester pioneered the field of System Dynamics, which could answer most of these questions. Thus, the industry and the economic governing bodies should have readily adopted the above offered solutions quickly. But it did not happen so. Forrester was too hasty in making comments such as management is still practised as a very skilled art and the scathing criticism on the conventional management science. He called the prevailing management practice an art and the associated science was ineffective in delivering the results. The reason for such a predicament was the lack of a unifying, underlying structure of fundamental principle, which did not allow managers, and teachers of management to appreciate the dynamic complexity of the systems. So the habit of thought practised was static than dynamic in nature.

Operations Research and Mathematical Economics as claimed by the lobby of economists provided the underlying foundation was negated by Forrester by stating that they are conspicuous in their failure to do so. He argued that mathematical economics and management science have been allied with formal mathematics than to economics and management. The evidence he advanced was the bias toward mathematical rather than managerial motivation that is seen in the preoccupation with optimum solutions. He explained the gulf between the practice and theory from the viewpoint of interests of managers and the academicians. A sharp and somewhat exaggerated distinction was drawn between the practising artists and preaching priests. He concluded that the art of practising managers was able to deal with decisions of great consequences better than the science offered by mathematical economists and industrial engineers. He listed a number of "obvious truths" which were accepted as the philosophical guidelines by management scientists in search of underlying scientific foundation and he proved that they were all misleading in different proportions. The above position taken by Forrester although is true, lacked its statesmanship. It brought out the political nature by denouncing the existing body of knowledge. Due to Forrester's stand on mathematical economics and resulting statements must have hurt the sentiments of persons of the stature Ansoff et.al., and the defensive posture taken by them in the article by Ansoff and Slevin (1968) is testimony to it. The political position assumed (may be inadvertently) by Forrester put a stumbling block to the progress of the study and the 80^{s} saw a little progress in comparison with the 60^{s} and 70$^{s.}$

System Dynamics and Learning Organizations:

Peter Senge (1990) produced an excellent work on system dynamics. By then, the technology required to model complicated systems considerably improved by bringing the computing department to the desktop. His thesis emphasised and reiterated Forrester's position on System Dynamics. The causes of many pressing issues from urban decay to global ecological threat lay in the very well intended policies designed to alleviate them. These problems were actually systems that lured the policy makers into interventions that focused on obvious symptoms, not the underlying causes, which produced short-term benefit but long-term malaise and fostered the need for more symptomatic interventions.

The motivation for him to believe in the subject was explained in his book Fifth Discipline. The most daring organisational experiments were foundering. Local autonomy produced business decisions that were disastrous for the organisation as a whole. Team building exercises only reduced the tone and tenor of arguments in business meetings but they remained fundamentally in disagreement on business issues. Companies performed as a great team during crises and then lost all the inspiration and got back to their positions when the business improved. Testimony for this is the great companies studied by Tom Peters while writing his Book 'In Search Of Excellence' remain petered out today. The above observations were enough to motivate a person to look for alternative ways. System Dynamics he believed is one. Finally, he recommends his book for learners especially those who are interested in the art and practice of collective learning.

The analogy of Mc Donnel Douglas DC-3 to learning organisations is a powerful concept. The DC-3 was made out of five critical component technologies and similarly learning organisations have to adhere to five disciplines viz., systems thinking, personal mastery, mental models, building shared vision and team learning. It is vital that all the five disciplines develop as an ensemble. The systems thinking is called the fifth discipline because it has the capability of integrating the remaining disciplines, fusing them into a coherent body of theory and practice. At the same time systems thinking also needs the disciplines of building shared vision, mental models, team learning and personal mastery to realise its potential.

The question 'does your organisation have a learning disability?' makes a powerful reading followed by the production-distribution game (named as 'Beer Game' in his book) mechanics and representative results. The seven disabilities such as I am my position, the enemy is out there, the illusion of taking charge, the fixation of events, the parable of boiled frog, the delusion of learning from experience and the myth of the management team and the beer game reinforce the fact that the existing knowledge is not enough to cope with the present day problems. Profound lessons learnt from these two initial chapters are the basic premises of system dynamics.

Premise I

> "Behaviour of a system is principally caused by the system structure, importantly the policies containing sources of amplification, time lags, and information-feedback".

Premise II

> “Systems are viewed most effectively in terms of common underlying flows of people, money, materials, capital equipment and information, tracing cause and effect chains through the relevant flow paths transcending the functional barriers”.

Premise III

> “Leverage often comes from new ways of thinking.”

Senge (1990) postulated eleven laws of the Fifth Discipline similar to which were presented by Forrester (1975) in his testimony before the subcommittee on urban growth of the committee on Banking and Currency in the House of Representatives. He called them as ‘Counter Intuitive Behaviour of Social Systems’. Social Systems belong to the class called multiple loop non-linear feedback systems. Human cognitive capabilities are limited to interpret complex feed back loops of social systems. The reason for this is our evolutionary programming has not endowed us with the skills to interpret properly the dynamic behaviour of social systems.

The first of the laws of the Fifth Discipline is that *‘today’s problems come from yesterday’s solutions’*. The most commonly stated difficulties in business organisations are market share erosion, low profitability or instability of employment. In these troubled companies people consciously try to solve the major problems to the best of their abilities. Policies are followed at various points in the organisations on the hope that they will alleviate the problems. In many instances, it emerges that the known policies describe a system that actually causes the problems. The known and well-intended practices of the organisation are fully sufficient to create the difficulties, regardless of what happens in the market place.

The second law is ‘*that the harder you push the harder the system pushes back’*. In a floundering company, while the system itself by its governing policies is moving towards the brink, the down-ward spiral develops in which the preserved solution makes the difficulty worse and thereby causes redoubling of the presumed solution.

The third law is that '*behaviour grows better before it grows worse*'. Low leverage interventions normally work but in the short-run often leading to much larger problems elsewhere in the long-run.

The fourth law is that '*the easy way out usually leads back in*'. We find comfort in applying familiar solutions due to availability of generally accepted definitions. Many undefined concepts are known to be of having major impact on the business such as integrity, loyalty, hope, confidence, motivation etc. Such variables must be provided definitions and the solutions must consider them where they are considered to be of critical importance.

The fifth law is a corollary to the fourth that '*the cure can be worse than the decease*'. Sometimes the familiar and therefore easy solutions are not only ineffective but also they are dangerously addictive. Most commonly found syndrome in the organisations is shifting the burden to the intervenor. Often a consultant is appointed to solve a problem and the problem recurs and the immediate response from the organisation is to call the consultant again.

The sixth law is that '*faster is slower*'. The generally accepted norm of growth for most of the industries, government agencies and individuals is fastest possible one. All natural systems have a rhythm of growth. The optimal rate of growth is far less than the fastest possible growth. The finest example can be found in the Peoples Express Flight Simulator by Sterman (1988).

The seventh law is that '*the cause and the effect are not closely related in time and space*'. Our experience from the contact with simple systems leads us to look near the symptom of trouble for a cause. Then we discover that the system presents us with an apparent cause that is plausible according to what we learnt from simple systems. But this apparent cause is only a coincident that is being produced by the feed back loop dynamics of a larger system.

The eighth law is that '*small changes can produce big results – but the areas of highest leverage are often the least obvious*'. This is the fundamental characteristic of business systems. All of the business systems seem to have a few sensitive influence points through which the behaviour of the system can be changed. These influence points are not in the locations that most people expect them to lie.

The ninth law is that '*you can have your cake and eat too – but not at once*'. There is usually a conflict between the short term and long term consequence of a policy change. A policy that produces improvement in the short run is usually the one that degrades the system in the long run. Many such dilemmas appear, as they are rigid and mutually exclusive choices because we are conditioned to think of what is possible at a fixed point of time. Process thinking skills will considerably improve with system dynamics perspective and result in finding the real leverage in seeing how the mutually exclusive choices can co-exist.

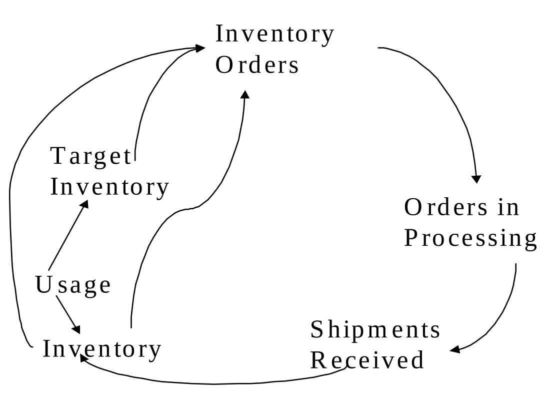
The tenth law is that '*dividing an elephant in half does not produce two small elephants*'. Nature integrates but never differentiates. The same is applicable to organisations. To examine critically the most compelling managerial issues in the organisation requires the skills of seeing the whole system that generates the issues.

The final and eleventh law is that '*there is no blame*'. This is the bedrock philosophy of System Dynamics. The system structure bears the responsibility of the system's behaviour. The structure is what we create and therefore the locus of responsibility lies with in the system than outside it.

Before the book Fifth Discipline by Peter Senge, System Dynamics was in hibernation for almost a decade. Senge must be credited for the effort of bringing forth the powerful subject to the large audience through his lucid exposition of the subject. The readership was much more than the previous elite club of system dynamics enthusiasts. This is evident from seminars in which it was considered fashionable to quote Senge and his book. The tragedy is that as Senge himself stated in his follow-up book Fifth Discipline Field Book (1994) that the most dangerous phase of a good work is that when the pioneer is respected. Senge was elevated to the status of the management gurus. So it is considered sufficient for teachers to state Senge's reference to getaway with mediocre understanding of the truth. Several readers admit that it is a difficult book to read. When confronted about the meaning further, they reveal that while all other things being alright, the most difficult part is the Fifth Discipline – The Systems Thinking portion of the book. While it is a fact that Senge brought to fore the Systems Thinking concepts quite powerfully, he failed to make the reader internalise the same or at least integrate it with the other four disciplines. One of the reasons for this is the oversimplification of the systems thinking through causal loop diagrams. Several people try to attempt systems thinking by drawing causal loops and end up drawing arrows all around making it spaghetti devoid of any meaning. The power of Senge's work is that it immediately enthuses all the management students alike. There is a trend by those who offer solutions in the name of learning organisations consider only the four disciplines that need not have any architectural support and leave the fifth discipline alone. Obviously, such interventions will not work which is equivalent to make DC3 to work with out the 'monocoque' technology. The information feedback loop is working here. The art is learnt by reading the book or attending a seminar, it becomes the basis for future practice of the art, and returns as the voice of experience to support future teaching.

Fifth Discipline received much attention both in academics and as a corporate tool for executive training. All the speakers about the learning organisations with reference to Senge, superficially appear very similar to dynamic thinking and yet educationally they move almost in the opposite direction. The fifth discipline emphasis is on the causal loop diagramming and not on the internal structure and its implications. In fact, the internal structure gets inadequate attention. The most conspicuous warping of reality in causal looping is in the direction of shortening the time constant of the system. Most managers think they can get the system responses much faster than that can be accomplished in reality. The causal loops by not having the capacity to show the time delays and sometimes shortening more than the managers already believe them to be, can only accentuate already existing misconceptions. For example, the inventory system is described in the Fig.2 with the help of causal loop diagram. The causal loop diagram in Fig.2 is static. There is no possibility of making out the determinant of the status of the system and which factor is changing the status of the system. The dynamic behaviour of the system can not be appreciated by looking at the causal loop diagram leave alone by a new comer to system dynamics not even by a seasoned system dynamics expert.

Fig.2 Inventory System Causal Loop Diagram



Causal loop diagrams lack the precision and details of the rate, level and auxiliary elements found in the flow diagrams. Flow diagrams bring about conceptual errors that do not readily show up in causal loop diagrams. For example, a causal loop diagram may inadvertently contain closed loops without levels. Such an error would be easily detected in a flow diagram. Flow diagrams yield considerably more information than causal loop diagrams about the system structure and associated dynamic behaviour. Because they depict the rate-level structure of the system, flow diagrams can often indicate possible types or modes of system behaviour. For example, the order of a system (the number of system levels) limits the possible behaviour modes of that system. Therefore, knowledge of the order of the system is essential in predicting the behaviour. Such information is explicitly contained in flow diagrams but not in causal loop diagrams.

Causal loop diagrams often also obscure information necessary for understanding the behaviour of an isolated feedback loop structure. For simplicity, causal loop diagrams frequently omit model structure such as delays and averaging processes. However, these processes embody negative feedback loops that could have considerable effect on the system behaviour. The flow diagram would call attention to these additional loops.

The habit wide spread in system dynamics is the use of causal loop diagramming. This habit led to dilution of the power System Dynamics had to offer. The analogy advanced is that causal loop diagrams provide the essential nerves, with out regard to the spinal cord, skeleton and organs. Drawing causal loop diagrams at the outset leads to static thinking or laundry list thinking undermining the very essence of dynamics. The causal loop diagramming before understanding the stock/flow structure and their interactions leads to the feeling of having achieved the objective which is true of most mapping languages. However, the causal loop diagrams have a very important purpose. They could well serve their purpose as communicating tool after having worked on the structure of the system and understood the behaviour of the system. Causal loop diagramming being a powerful communicating tool works as a double-edged sword. On one side, it increases the understanding the behaviour of the system considerably and on the other, it stymies the very thinking process if done prematurely.

Throughout his book Senge tried to communicate the power of systems thinking with the help of causal loop diagrams. The technology on which the whole system dynamics rests was ignored. There was only a small chapter 'Microworlds; The Technology of Learning Organisation' appears almost at the end of the book. This type of treatment given to the subject only made it a display of a powerful tool but devoid of the methods to use it.

Systems Thinking:

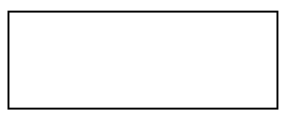
Richmond (1994) pleaded that we must learn how to operate with in a new highly interdependent reality considering the long term more seriously. Two principal barriers to learning were identified as the local spatial and temporal orientations due to our evolutionary programming thinking skills. Due to this orientation, three habits of thought viz., thinking statically than dynamically, assigning responsibility for performance to factors outside the system than looking inward and finally, thinking correlationally than operationally take deep roots. Richmond explains further why such barriers to learning remain and he blames the existing technology and mapping skills. He is quite critical of the spreadsheets that he calls an excellent facilitator of "laundry list thinking/factors thinking". They have all the learning disabilities of being static in nature, externally focussed and correlational in decision support. Spreadsheets in any form that are so pervasive in business today can not reveal the process of how we got to the end result. They are extremely handicapped for simulating the dynamic unfolding of process performance. Therefore, they initiate one to blame external factor for poor performance and draw conclusions on the correlations. They have little utility in process of strategy redesign/business process reengineering.

The mapping tools are commonly used in business process reengineering projects. Mapping is normally engaged in teams. The mapping activity generates a set of process charts of the underlying processes operating with in the organisation or of the underlying premises constituting strategy. They differ in details from high level over-views to minutest movements. Since teams, which are drawn from different functional affiliations do the activity of mapping, the language used must offer a set of symbols that transcend the boundaries of these representing functions. The second requirement for mapping languages is continuity of purpose. Each team builds upon the predecessors' efforts. Therefore, it is critical that mapping languages have a rigour of a discipline to them. Finally, the mapping languages should have the capability of linking maps to the dynamic behaviour of the process. Maps in their existing form are therefore static in nature. The way out is the systems thinking. The systems thinking paradigm dictates a particular language, the language of stocks and flows. This language makes possible the application of systems thinking method.

What is Systems Thinking:

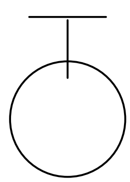
Systems thinking is composed of four major components: Paradigm, language, method and technology. The systems thinking paradigm requires the development of four interdependent thinking skills. They are dynamic thinking, system as cause thinking, operational thinking and closed loop thinking. Taken together these skills make up a consistent learning process. Dynamic thinking helps to look at the problem over a period of time than at a specific moment of time. This enables the managers to move the focus from individual events to pattern of behaviour. It transcends the static and snapshot picture offered by spreadsheets. System as cause thinking is used to draw the boundary around the relationships that lie in the system. This skill enables to see that the system itself bears responsibility for the behaviour. Operational thinking prompts one to ask the question: how does the system work? This is what is termed by Richmond as 'plumbing' or 'physics' of the system. This is crucial to systems thinking because operational thinking is used to make our mental models explicit. Finally, closed loop thinking is used to draw the feed back relationships. One needs to develop and master each of these critical thinking skills to become a systems thinker.

The Systems Thinking language is made up of only four symbols. This economy greatly enhances the clarity and precision in both thought and expression. Stocks, flows and connectors are the essential building blocks for representing the way dynamic systems really work. Stocks represent accumulations both physical and non-physical. They depict condition with in the system. Stocks exist at a point of time. When the action is frozen, what persists is a stock. They are exemplified by balance sheet items, head count, backlog of orders, customers, knowledge etc. They are given a symbol of a rectangle.



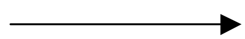
Stock

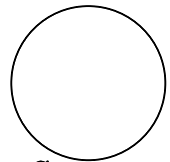
Flows represent activities. Activities change states. If stocks are seen as nouns of a language, flows can be identified with verbs. Flows exist over time. Flows are the decision variables. Examples of flows can be found in Profit and loss accounts items, hiring, ordering, shipping, producing, changing price, learning etc. They are given a symbol of a valve.



Flow

Connectors carry the information that serves as inputs to flows. They are necessary to represent feedback relationships. Connectors are not inflows but are inputs. Converters are catchalls. They store constants, perform maths and make graphical relationships easier to include in the model. Connectors are arrows with the head pointing towards the item in the model stating the relationship and circles represent the converters.





Systems thinking method is learning in progression. It is a way to develop a deeper understanding of the systems with in which we live. It comprises of identifying the reference pattern of behaviour. Using the system as cause thinking and operational thinking skills, build hypothesis and test the hypothesis. Finally, identify the leverage points to correct the system structure to display desired behaviour pattern.

Systems Thinking is a package that improves the quality of the mental models people construct and the accuracy of the associated simulations of these mental models. The technology used is the computer simulation due to inherent deficiencies of human cognitive capacities that can not intuit the dynamics. Computer simulation compresses time and space. Actions that produce immediate consequences in space and time can serve as the basis for reflection and learning which in turn can lead to changes in actions. But because some of the consequences of our actions fall outside our normal bounds of learning, they can not serve as a basis for modifying our behaviour. Computer simulation acts to compress time and space and in so doing makes the delayed consequences of our actions available as a source of learning. Another motivation for use of computer simulation is that it increases the likelihood of drawing the correct inferences about the dynamic behaviour that is implied by the given structure.

Facilitators for System Dynamics Studies:

System Dynamics and the associated technology available was DYNAMO on a mainframe computer. For instance, a simple inventory system as seen in the preceding sections needs the following codes to be written.

DYNAMO EQUATIONS:

INV.K=INV.J+DT (OR.JK-SR.JK)

INV=DINV

INV=Inventory (UNITS)

OR=Order Rate (UNITS/WEEK)

SR=Sales Rate (UNITS/WEEK)

DINV=Desired Inventory (UNITS)

SR.KL=STEP (20,4)

Sales will step up in the week 4 to a level higher by 20 units.

DISCR.K=DINV-INV.K

DINV=200

DISCR=Inventory Discrepancy (UNITS)

OR.KL=FOW*DISCR.K

FOW=0.5

FOW=Fraction Ordered per Week

DT=0.1

PLTPER=0.5

LENGTH=20

PLOT INV=I(0,200)/SR=S,OR=O(0,20)

DYNAMO takes the equations in a rigid form. It is a job of a trained professional in DYNAMO to write complex programs. The syntax and converting the flow diagram to equations form leads to a specialisation. There are other modelling software packages available with capabilities to create the models and management flight simulators (MFS).

Microworld Creator is a modelling software and basic MFS, which works on Macintosh personal computers. Most of the MIT flight simulators, including the People Express Flight Simulator were created with it. The interface is separated into four boxes. The first lists the input variables, the second lists custom designed reports consisting of text, graphics and values, the third lists the plots and tables and the fourth is the display area for reports, plots and tables used by the participant.

*S**4* is a sophisticated flight simulator and executive strategy system operating on Macintosh. It is more sophisticated and complex version than Micro World Creator. It has the same basic interface, divided into four windows. It included many more features including the ability to use arrays and a lens feature that makes it easy to trace through the cause-and-effect relationships in the model and track down unusual behaviour.

Ithink Core Version is a modelling software, which works on both Macintosh and Microsoft Windows. Because of its powerful features and ease of use, *ithink* is one of the most popular system dynamics modelling tools. It allows drawing stock-and-flow diagrams on the computer screen, completely mapping the structure of the system before the entry of the equations. More detail can be added and group the elements into submodels. Zooming in facility is available to view the complex models. *STELLA II* is similar software designed for academic use.

Ithink Authoring Version is modelling software and has sophisticated capabilities for management flight simulators available on both Macintosh and Microsoft Windows. This version has the ability to customise and control the user's MFS experience. Some of its features include the ability to have messages displayed when certain conditions are met. Exploration of the systems structure through mapping tools in browse mode allows users to interact with the model with out being able to change the structure of the model. The navigation capabilities allow the user to control the pace and direction of their interaction.

Powesim is modelling software with basic MFS on Microsoft Window platform. *Powersim* is a flow-diagram-based modelling language that has the ability to open multiple models simultaneously and connect separate models to each other. Using the slide buttons basic MFS can be built and the slide buttons can be used to control the input and reports. Causal loop diagrams also can be added as form of on-line documentation. A more sophisticated authoring tool of the same family is *Mosaikk-Sim Tek* a Microsoft DOS based system. *Mosaikk* is a very sophisticated authoring tool for the PC that can run video CD players. It connects directly to *SimTek*, a *DYANAMO* –like modelling language with a great deal of versatility.

Vensim is a modelling and sophisticated management flight simulator working on the Microsoft Windows platform. *Vensim* is a powerful model development language for the PC and Unix systems. Modelling begins by using a sketch tool to enter the causal loop diagrams, which will become the basis of the model. *Vensim* automatically documents the model as the model building activity progress by creating trees that allow tracing cause-and-effect relationships throughout the model. It offers sophisticated statistical and graphics features and allows the user to create menus, input screens and text screens to help guide users through the flight simulator.

Professional DYNAMO Plus (PD Plus) is a modelling software available as the MS-DOS version. *PD Plus* allows to build extremely large models sometimes up to 8,000 equations with a wide variety of programming features. However, the system equations have to be typed in based on the flow diagrams drawn on the paper. *PD Plus* may have a daunting learning curve, but most of the literature in the systems dynamics uses the *DYNAMO* language, large number of models can be studied. *DYNAMO* for Windows has the basic flight simulator features and allows the models developed in the *PD Plus* to be attached as basic flight simulator interfaces. Text can be included to introduce and document the model, and custom designed reports can be created. The user finds it convenient due to the formats used are very much similar to balance sheets and other similar formats in use in the business. The following table shows the appropriate combinations of the software packages.

	Modelling Software (used for building underlying model of the system)	Basic MFS Language (used for building simple microworlds)	Sophisticated MFS Language (used for highly interactive, graphically sophisticated microworlds
Macintosh Software Combinations	Microworld Creator	Microworld Creator	
	Ithink (core version)	Microworld Creator	
	Ithink (authoring version)	*Ithink* (authoring version)	
	Ithink (core version)		S**4 and HyperCard
	Ithink (core version)	S**4	
MS-DOS and MS Windows software combinations	*Ithink* and STELLA II	*Ithink* and STELLA II (authoring version)	
	Powersim	Powersim	
	Vensim	Vensim	
	Professional DYNAMO Plus	DYNAMO for Windows	Mosaikk and SimTek
	SimTek		Mosaikk and SimTek

With the new software packages like *ithink or vensim* ,and the like one has an idea and the structure of the system with a bit of help from the facilitator can be built in a fraction of the time that is required by the previous technologies. It made a highly skilled part of the discipline simple and brought it to everyone's reach through a single mapping tool and associated dynamic simulation. The inventory system equations in DYNAMO can be represented by a flow diagram as shown in Fig.3. The flow diagram not only creates the required algebra as in the DYNAMO by the computer but also overcomes the shortcomings of the causal loop diagrams. It translates the mental models by defining the boundary of the system, clarifying the physics of the system and relating to the dynamic behaviour of the system. Both the above capabilities foster accelerating organisational learning.

Definition of Systems Thinking:

Richmond (1997) provided a succinct definition for Systems Thinking. Forrester named the new science he pioneered as Industrial Dynamics. After a while he realised that Industrial Dynamics is a misnomer. The name thus changed to System Dynamics. Richmond found this name also not exactly reflecting its true essence, called the discipline Systems Thinking. The definition of systems thinking is given as follows:

> "The art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure"

The art and science is composed of two components viz., Paradigm and Learning Method. The paradigm conditions the learning method and in turn learning method supports the paradigm. The paradigm further consists of two sub-components such as vantagepoint and thinking skills. Systems Thinking when embraced, people position themselves such that they can see both the forest and the trees. Structurally, they will be able to see both the generic and the specific and behaviourally, they can see both the pattern and the event. Having got to the vantagepoint, by embracing systems thinking, people will be ready to use a set of thinking skills. The set of three systems thinking skills are systems as cause thinking closed loop thinking and operational thinking. The first two have amply recognised as the core skills of System Dynamics. The third skill, the operational thinking has been the frontier area of Richmond's thesis (1997). Rightly it was argued that lack of appreciation of this third skill, operational thinking caused (inadvertently) to dilute the essence of System Dynamics power.

Richmond has clarified what is not Systems Thinking. Systems Thinking is not general systems theory, nor is it 'soft systems' or systems analysis. It shares elements in common with all of these. He further states that these disciplines and approaches have much to contribute and we should celebrate synergies and avail ourselves of cross-fertilisation opportunities. Richmond pleaded that Systems Thinking is quite unique, powerful and broadly useful as a way of thinking and learning. Systems Thinking is capable of being transparent – seamlessly leveraging the way we learn business management. We need to concentrate on realising the potential in front of us for so many years.

Conclusion:

Forrester pioneered the discipline Industrial Dynamics and later corrected himself and rechristened it as System Dynamics. While reaching out, he took up an extreme position of denouncing the existing knowledge of mathematical economics and operations research. The timing was such that when the OR and MS were at the peak of their glory. Further, the language that was offered for mapping processes was causal loop diagramming followed by flow diagramming. This mapping further translated into a complex computer code for DYNAMO. Such a circuitous route did not evoke positive response from business leadership. As a matter of fact System Dynamics became the victim of politics and remained the domain of a few select elite of System Dynamists at MIT.

Senge after a lull of almost a decade came out with his best seller; The Fifth Discipline. With all his good intentions to reach out to business world at large met with little success. The reason for this could be two folds. One, oversimplification of systems thinking skills that integrate the remaining four disciplines. The second reason is that natural tendency for those not aware of System Dynamics to conclude that mapping the processes with the help of 'system archetypes' is the end of the process. Since they do not explore the dynamics of the system, they take the liberty of intuiting the dynamics with out realising the counterintuitive behaviour of the social system. The very foundation of System Dynamics is that human mind can not intuit dynamics but good at building the structure. Both the human mind and the computer could complement each other to produce the desired learning in the organisations. By relegating the computer simulation (microworlds) to background the essence of System Thinking could not be brought to the fore.

Richmond advanced the Systems Thinking definition from System Dynamics. The graduation from Industrial Dynamics to System Dynamics to Learning Organisation to Systems Thinking is quite a long journey. He advanced the theory of operational thinking the most vital component of learning technology that was taken for granted in the past. The learning method is the process of putting the infrastructure through stocks and flows together, in other words, plumbing or looking at the physics of the system. All mean essentially operational thinking. The language needs to represent the operational thinking and must celebrate the economy of symbols for using in cross functional teams with out loosing generality and they must have the continuity of purpose and finally they must be able to link the structure to dynamics of behaviour of the system. The competent skills required to make a DYNAMO program was automated and the computer generates the algebra while the structure is being mapped by the cross functional teams. With the advent of the technology like *ithink* which is as simple to boot as Spreadsheet enables everyone from different disciplines to check their strategies and provide the much needed laboratory support for their decisions. At the same time if the Systems Thinkers take positions more like statesmen without bickering on the territorial imperatives it would be a great tribute to Forrester the pioneer of the field after 40 years of his offer to the world a science which is likely to make the business management less of an art.

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