Cybernetics in Soft Systems: Developing a System Dynamics Model of an R&D Organizational System in India

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Abstract

The study reported in the paper has focused on the identification and analysis of various causal linkages that exist in the soft systems that operate within a larger R&D organizational system and the development of a system dynamics model based on these linkages. The Council of Scientific and Industrial Research (CSIR), a public-funded R&D organizational system in India with its constituent laboratories, has been considered for the study. Multiple regression analysis was employed to understand the influence of integration, coordination, and interdependence of research units or groups on quality performance of these units working in CSIR laboratories. In another study, the multivariate relationships between the availability of resources (material, human, organizational), and R&D effectiveness of research units were explored. Two other sets of studies were carried out to complement the above. In the first study, the factors and forces that motivate the scientists in the R&D work situations and those that contribute to the overall satisfaction of the scientists with their work groups were explored. The second study has assessed the use of mental energy by scientific personnel working in three CSIR laboratories with the objective of increasing the energy count for improving organizational effectiveness. Finally, a system dynamics model incorporating these feedback influences has been developed for the overall R&D organizational system.

Keywords: Casual linkages; Cluster analysis; Multiple classification analysis; Regression analysis; Soft systems; System dynamics model

1. Introduction

Strategic management of research and development (R&D) organizations has assumed importance in recent times. Hamel (1998) has argued that in this discontinuous world, strategy innovation is one of the keys to create wealth. Strategy innovation is the capacity to re-conceive the existing industry model in ways that create new value for customers, wrong-foot competitors, and produce new wealth for all stake-holders. It stresses upon resource creation, vital for success in the face of resource disadvantages. Thus, unique resources could provide competitive advantage if they are non-tradable, non-imitable and non-substitutable. The human resource is one such resource. In such an environment, maintaining credibility would require managers of R&D organizations to leverage internal R&D capabilities with external resources, deliver long-term as well as short-term value, facilitate rapid learning, and to focus on speed in commercialization of new technology. Designing an organizational system that could motivate R&D scientists to give an improved performance is a step in that direction. The study reported in the paper attempts to do just that considering the laboratories functioning under the largest public-funded R&D laboratory system in India, the Council of Scientific and Industrial Research (CSIR), India, as a case and analyzing the casual linkages that exist among the components of such a system.

A review of Hughes productivity study (Ranftl, 1989) has shown that skilled responsible management is one of the most important factors in achieving high productivity in technology-based organizations. The study has identified 25 factors that are most likely to cause counter-productivity within R&D organizations. Among these factors are ineffective planning, direction and control; poor internal communication; poor psychological work environment; insufficient attention to employee motivation; misemployment; ineffective structuring of assignments; ineffective customer interface; and ineffective engineering/production interface. Tishler, Dvir, et al. (1996) have adopted multivariate statistical methods to analyze 110 defense projects executed in Israel with a view to identify managerial variables that are critical to the success of defense pro-
jects. Shenhar, Tishler, et al. (2002), considering a sample of 127 projects, have carried out multivariate statistical analysis to probe into the factors that affect success/failure of these projects.

The term innovation could be used in two different ways. Innovation, as a process, is the creation of new products or services or enhancements to existing products or services; or the creation of organizational processes that have a significant impact on a person, group, organization, or society (Higgins, 1996). This is in reference to the latter connotation of organizational innovation that we strive in this paper to investigate into the causal relationships among the factors in the work climate, the effectiveness measures, and the organizational, material, and human resources. Organizational culture within the R&D unit is a key driver of innovation (Judge, Fryxell and Dooley, 1997). If we aim to improve organizational performance in various dimensions, such relationships would serve as guiding principles for any organizational intervention. With this perspective, a set of four separate studies carried out in different laboratories functioning under the CSIR are described below. Each such study focuses on a certain aspect of the R&D-innovation process in these organizations and, as mentioned above, these are finally linked together to form a system dynamics model of the R&D organizational system.

The research focus in the present paper is on the soft system, the human activity and relationships within the hard system – the technology based structured organization, in particular the R&D organizational system. It is important to note that soft system management emerged from the failure of system engineered concepts to be applied to the resolution of ‘messy’ people based organizational problems (Bolton and Gold, 1994). System dynamics and the other problem-solving and soft system methodologies have grown up separately, and yet they have many things in common, perhaps the most important being a concern with effective organizational intervention.

Soft variables could be defined as the ones that cannot be measured the hard way, that is, directly. These variables are measured indirectly by peer evaluation – often by using rating instruments in a questionnaire, a method known as quasi-quantitative measurement. Developing system dynamic models incorporating such variables are problematic. First, there is the problem of measurement of these variables with the related questions of reliability and validity of these measures (Roy and Nagpaul, 2000). Roy and Mohapatra (2002) have suggested interfacing system dynamics and structural equation modeling to address the issue of reliability of such models. Such problems also beset the effectiveness measures of R&D systems (Roy, Nagpaul and Mohapatra, 2003).

In the light of the above discussion, the present paper attempts to model the human resource organizational system in CSIR laboratories using a system dynamics framework. The causal linkages among the variables within such a system were ascertained through a series of separate studies carried over time focusing on specific sub-themes. These are then integrated to build up the system dynamics model.

It may be noted that the structure of the data is such that multilevel analysis are both useful and feasible. Because the data were collected from several members of the same organizational entity - the research unit - and because of the specific pieces of information concern that entity, it is logical to consider the data at both the respondent level and the unit level. The first two studies and a part of the third study are at the research unit level and the rest are at the individual scientist level.

Council of Scientific and Industrial Research (CSIR), India

CSIR is an autonomous society under the ‘Societies’ Registration Act, 1860,’ with the Prime Minister of India as its ex-officio President. CSIR laboratories cover a wide canvas of disciplines. The CSIR has in its fold 40 national laboratories and a number of field stations working in different fields of R&D spread all over the country. Its intellectual property policy emphasizes the need to maximize the benefits from its intellectual capital by stimulating higher levels of innovation (CSIR, 1996). The CSIR enters into bilateral agreements in the fields of pure as well as applied science with the scientific organizations of various countries.

2. The First Two Studies

The first study seeks to relate the influence of coordination, integration, and interdependence on the level of quality performance of research units or groups and the second study seeks to identify and assess the important organizational, environmental and other input factors that influence the performance-effectiveness of research units.

The fundamental observation that led to a focus on research units was that significant modern R&D is generally (but not always) conducted by groups of individuals. Furthermore, most modern R&D is supported and administered through some form of organization that focuses on clusters of people, not on single individuals. Given that most R&D output is the joint product of several minds, and of complementary skills and efforts, it seemed reasonable to examine directly the entity that is the actual producer of research and/or development.

A research unit has been operationally defined in
the study as one that has the following characteristics: (1) it has at least one project in the unit; (2) it has a total expected life span of at least one year; and (3) it is comprised of at least three core members, among whom there is one scientist who is the head of the unit (a core member is an individual researcher or a technician who devotes at least eight hours per week to the work of the research unit and who has direct or indirect communication with the head of the unit at least once in a month). In line with the observations sketched above, it was expected that most of the more significant R&D activities carried out within the modern world would be conducted by groups of individuals who met the criteria for a research unit.

2.1. Selection of Research Units

Adopting a two-stage random sampling design, 250 research units were selected from across the laboratories functioning under the CSIR in India. Subsequently, usable data were obtained from 236 research units. Again, for each sampled research unit, samples of core members were selected at random subject to a maximum of three scientists/engineers and three technicians. The data were collected through a set of standardized questionnaires that were administered to the head of the unit, the staff scientists, engineers and technicians of the research unit and external evaluators. There were in all 834 respondents; of these 236 were heads and the rest scientists, engineers and technicians.

3. Study 1: Influence of Coordination, Integration, and Interdependence on Quality Performance

A research unit is considered as an organizational system and its performance needs to be evaluated in terms of a general system model. A comprehensive evaluation of a research unit will require the assessment of (a) unit’s output in terms of quantity, quality, cost, acceptance and related criteria; (b) unit’s ability to adjust to internal changes and successful adaptation to externally induced changes; and (c) level of internal strain and conflicts between members of the unit. This conceptualization is based on the model proposed by Georgopoulos and Tannenbaum (1957). However, only qualitative performance measures have been considered in the present study.

Modern scientific research has become an organizational enterprise in which scientists of various disciplines collaborate in search of solutions to complex problems (Hagstrom, 1964). Farris (1973) in his study on NASA research teams has found that more innovative teams had better collaboration among members than less innovative terms, suggesting that mutual adjustments might in fact be the controlling factor.

3.1 The Indices

All the latent constructs have been measured on a 5-point scale (5 representing high value and 1, low value). In general, the indices were constructed by pooling the scores of the unit leader and those of the scientists of the respective research units.

‘Coordination’ as a factor has received much attention from organizational theorists, but few of them has defined the concept. There could be two types of coordination — coordination by feedback and coordination by planning. Coordination by feedback involves transmission of information, whereas coordination by planning involves the process of decision-making and planning. Following this concept, coordination within each research unit was tapped by the following items:

- Information about on-going research programmes.
- Coherence of the research programmes of the unit.
- Adequacy of research planning in the unit.
- Information on research planning at unit level.

The internal reliability of the index was tested by Cronbach alpha, which was 0.83.

Little empirical evidence is available in the literature on either the characterization of ‘integration’ or its relationship with other organization variables. Fullan (1972) has defined integration as the extent to which people perceive themselves as isolated or linked together through interactions. In the present study, the concept of integration is developed based on the theory proposed by Katz and Kahn (1966) and Georgopouls (1972) on organization as a social system. The underlying assumption in this conceptualization is that if an organization is highly integrated, that is, if there is a high degree of psychological binding between the members on the one hand and the total organization on the other, it would have a significant effect on organizational performance. To make this concept operational, two components of integration have been framed in this study. The first component is called ‘member-member integration’ and the second concept is called ‘member-system integration’. According to Hall and Lawler (1970), when individual members are highly integrated into an organization, they tend to perform better and are also more willing to offer their capabilities and efforts to the organization. The index of integration (Cronbach alpha = 0.79) was made operational by the following items:

- Spirit of innovativeness in the unit.
- Spirit of dedication to work prevailing in the unit.
- Cooperation among scientists in the unit.
- Attachment to the unit.
- Leader’s support to scientists’ work.
- Interest and excitement of research activities.

Various studies have investigated the relationship...
of task ‘interdependence’ and other organizational variables (Van de Ven et al., 1967). Both coordination and integration are essential to the effective functioning of an organization and to achieve system outputs. Coordination and integration depend upon the degree of interdependence that exists in the organization. In the present study, the concept of interdependence has been judged in terms of the tasks and the objectives of the groups and of the overall organization. The first one, task interdependence, represents the extent of contingency among tasks such that the completion of each will have certain consequences for the completion of the others and of the total operation. The second one, objective interdependence, represents the extent of contingency among the objectives such that the attainment of each will have certain consequences for the attainment of others and of the overall organizational goals. The specific items for the index of interdependence (Cronbach alpha = 0.77) are:

- Scientific/technological objectives of the unit are closely related.
- Nature of the research work in the unit is such that it requires extensive cooperation among the members of the unit.

The index of quality performance of the research units is based upon qualitative ratings of the following:

- Unit’s productiveness in the sense of adding to the store of knowledge, methods or inventions to its field.
- Innovativeness in the sense of generating new ideas, approaches, methods, and applications.
- Contribution to the scientific and technological development of the field.

This measure is based on the judgment of external evaluators and the scientists’ self-reported performance. For external evaluation, only those evaluators, who felt knowledgeable about the unit’s work, were asked to assess its performance. A composite index was constructed by summing up the scores of each evaluator and taking the average. The value of Cronbach alpha for this index was 0.84.

3.2 Results

Multiple regression analysis was adopted to test the relationships among the variables. The results are presented in Figure 1. Direct and indirect influences of all variables are given in the Figure. When a variable indirectly affects another variable through an intermediary variable, it is known as an indirect influence. Direct influence of variables is indicated outside the brackets, which is the same as standardized partial regression coefficient. Indirect influence of variables is indicated within the brackets. It can be seen that coordination is influenced equally by interdependence and integration, but the influence of integration on coordination increases significantly, if it is coupled with interdependence. The direct effect of integration on coordination, keeping the influence of interdependence controlled, is highly significant ($\beta=0.52$). The indirect effect of interdependence on coordination, if it acts through integration, is also significant (0.17). Integration and interdependence jointly account for about 55 per cent of the variance in the level of coordination ($R^2=0.55$). This shows that although integration and interdependence independently influence the level of coordination significantly, the joint effect of interdependence and integration on coordination is much more pronounced. These results support the viewpoint that coordination is a result of integration and interdependence.

It is also observed that independently integration has more influence on quality performance than coordination, if other variables are kept controlled but both integration and coordination are related significantly to quality performance. Further, it is evident that indirect effect of integration and interdependence on quality performance through coordination is much more significant. Interdependence acts only indirectly on quality performance through its influence on integration and coordination. It is also observed that independently integration has more influence on quality performance than coordination, if other variables are kept controlled but both integration and coordination are related significantly to quality performance. Further, it is evident that indirect effect of integration and interdependence on quality performance through coordination is much more significant. Interdependence acts only indirectly on quality performance through its influence on integration and coordination.

![Figure 1. Relationships between Organizational Variables and Quality Performance](image-url)
Thus, scientists working under highly coordinated conditions exhibited a high degree of interdependence and integration. Integration and interdependence also have independent impact on coordination, with the former influencing attitude and the latter influencing task interdependence. Further, research units rated high in quality performance tend significantly to be more integrated and coordinated.

4. Study 2: Influence of Organizational, Material and Human Resources on R&D Effectiveness

The various resources available to a research unit can be classified into three broad categories – material resources, human resources and organizational resources. The material resources comprise scientific equipment and materials, laboratory space, technical services and other infrastructural facilities such as library and information services, data processing services, workshops, etc. The availability of scientific equipment can be constrained by a number of factors, such as inadequacy of financial resources, delays in decision-making and implementation caused by cumbersome rules and procedures, problems of maintenance of equipment, scientists’ resistance to sharing of equipment etc. The human resources are among the most important resources of the research group, whose performance would depend essentially upon the quality of scientific and technical (S&T) manpower, their motivation, and their morale.

4.1 The Indices

As in Study 1, all the latent constructs have been measured on a 5-point scale (5 representing high value and 1, low value). As before, the indices were constructed by pooling the scores of the unit leader and those of the scientists of the respective research units.

The index of research planning quality (Cronbach alpha = 0.85) was tapped by the following items:

- Quality of conception of the research programmes.
- Conceptual challenge of the research activities.
- Degree of coherence of the research programmes.
- Degree of congruence of S&T objectives of the research work performed by the research unit.

The rest of the indices, that is, financial resources, library and information services, technical services, and data services, are all single-item indices.

Among the various non-material resources, communication is one of the important predictors of R&D performance. Several studies indicate the importance of communication with scientific community, both in immediate work environment and outside (Ebadi and Utterback, 1984); (Fisher, 1980). Diversity of communication and particularly communication with scientists outside the specialty of the researcher are important for getting new and novel ideas for research. The index of communication (Cronbach alpha = 0.81) includes the following components:

- Frequency of contacts with the supervisor.
- Effect of contacts with the supervisor on S&T performance of the respondent scientist.
- Opportunities for contacts with members of other research groups within the institution.
- Opportunities for contacts with researchers in other institutes working in the same field.

The index of human resources (Cronbach alpha = 0.78) includes the following components:

- Degree of satisfaction with the human resources available to the unit as compared with its current research activities.
- Degree of satisfaction with training and career development facilities to the unit’s members.

The index of scientific equipment (Cronbach alpha = 0.83) was tapped by the following items:

- Degree of satisfaction with the quality and quantity of scientific equipment.
- Degree of satisfaction with the way in which scientific equipment is shared within the research unit.

The index of R&D effectiveness is similar, but not the same, as quality performance described in Study 1. As may be observed, the item ‘contribution to the scientific and technological development of the field’ has been substituted here by the item, ‘usefulness of the work of the research unit to meet the institute’s R&D objectives’.

This index was tapped by the following items (Cronbach alpha = 0.76):

- Usefulness for the work of the research group in helping the organization, to which it belongs, to carry out its objectives with regard to R&D.
- Innovativeness of the research group in generating useful new ideas, approaches, methods, inventions, or applications in its field of work.
- Productiveness of the research group in the sense of adding to the store of knowledge, methods, or inventions in its field of work.

4.2 Results

To assess the role of human and organization resources vis-à-vis material resources with R&D effectiveness as the dependent variable, multiple classification analysis was carried out with material resources as the background variables and human and organizational resources as the intervening variables. The results are presented in Table 1 where $\eta^2$ is the proportion of variance in the dependent variable explained by a predictor and $\beta$ is the measure of relationship between a predictor and the dependent variable after holding the other predictors constant.
It is observed that organizational resources are the most important set of predictors, followed by human and material resources. The most important predictor is research planning quality that explains 31% of the unadjusted variance in the dependent variable. Thus, in the management of R&D, the importance of effective planning for research and development activities can never be underestimated.

All the predictors in Table 1 together explain 31% of the adjusted variance in the dependent variable. If the different material resources are the only predictors of R&D effectiveness, then all these predictors together explain 9% of the adjusted variance in R&D effectiveness (done separately, not presented in Table 1). Therefore, the addition of human resources and organizational resources to the material resources increases the value of adjusted $R^2$ by 22% which is quite substantial. This underscores the importance of the intervening variables in explaining the performance of the research groups over and above what can be explained by the material resources. Thus, managing R&D must go beyond a simple cost-benefit approach to entail the determinations of optimum organizational, managerial and social-psychological conditions for successful conduct of R&D.

5. Study 3: Work Environment in CSIR Laboratories

The particular study was carried out by Roy and Dhawan (2002). Examination and evaluation of work environment in R&D laboratories enables one to formulate strategies that can improve the behavioral aspects in institutional functioning and effective organizational performance. The study reported the findings of an empirical research on the factors affecting motivational levels of scientists working in the laboratories functioning under CSIR, India, and the factors contributing to the overall satisfactions of these scientists with their work groups.

The dimensions of work environment in the laboratories have been divided into two categories (1) related to the overall organizational system; and (2) related to the work groups.

The set of factors affecting the work environment of R&D organizations forms an important subset of a larger body of literature on the management of these organizations. Litwin and Stringer (1968) have focused on the consequences of organizational climate for individual motivation, thus supporting the general idea that climate encompasses both organizational conditions and individual reactions. Thus, the climate is often considered as relatively temporary, subject to direct control, and largely limited to those aspects of social environment that are consciously perceived by organizational members. Pelz and Andrews (1966) in their have study found that the ratings of the respondents (more than 1300 American scientists) on dedication to their work showed significant positive relationships to both ratings of performance and the actual output of scientific products. They have also observed that the performance of the scientists increased when tasks like decision-making and goal-setting were carried out in a participative fashion.

Regarding R&D work groups, quoting from a few earlier studies, Jain and Triandis (1990) have observed that in high innovation groups, the supervisors were more active participants in the informal organization. Pelz and Andrews (1966) have found that the performance of scientists was high when they experienced a sense of belonging to a group, headed by a competent leader.

Three laboratories functioning under CSIR, namely, Central Food Technological Research Institute, Mysore (say Lab-1); Indian Institute of Chemical Technology, Hyderabad (say Lab-2) and National Chemical Laboratory, Pune (say Lab-3) were selected for the study. The scientists were chosen using systematic random sampling, with every third scientist from the standard random list. In all, 208 scientists from the laboratories had participated in it.

5.1 Results: Related to the Overall Organizational System

The response to the first part of the questionnaire was subjected to cluster analysis, with ‘motivation’ as the central factor. Our aim in this analysis was to understand the factors necessary to provide a work environment that will motivate the scientists in their work situations. There were 19 questions related to eight work environment factors in the questionnaire: human resource primacy, communication flow, decision-making practices, technological readiness, senior sci-
entists’ influence, junior scientists’ influence, goal clarity, and motivational conditions.

The results are presented in Figure 2. It is observed from the Figure that the three factors common to the laboratories are: human resource primary, communication flow, and decision-making practices. In addition to these three factors, goal clarity has been found to be important in Lab-2 and Lab-3 and technological readiness in Lab-2, as factors related to motivation. The general inference is that in case the management of an R&D organization wishes to activate and motivate the scientists to put up a better performance, it is imperative that a suitable system of decision-making involving scientists at different levels, and a proper system of communication be developed. In his study, Allen, quoted by Jain and Triandis (1990), has found that even during the problem-definition stage, personal contacts more than five times the number of messages supplied by written sources. Therefore, communication through personal contacts is a crucial aspect of the innovation process.

5.2 Results: Related to the Work Groups

The second part of the questionnaire was related to work group processes containing nine questions related to eight factors: coordination, group decisions, knowledge of the job, information sharing, motivation to achieve objectives, group adaptability, confidence and trust, and overall satisfaction with the work groups. In order to understand the factors and forces that contribute significantly to the overall satisfaction of the scientists with their work groups, stepwise regression analysis was carried out.

The results are presented in Table 2. It is observed from the Table that scientists from Lab-1 have perceived three key factors - information sharing, group adaptability, and making group decisions as explaining the variance in their overall group satisfaction. For Lab-2, the significant factors are: confidence and trust, group adaptability, and making group decisions, a new factor being confidence and trust among the group members. Yet another new factor that has been observed for Lab-3 is coordination among various functions performed by the work groups. This is perhaps more due to the interdisciplinary and multidisciplinary nature of modern R&D where a participative group decision-making mechanism and a higher level of confidence and trust among group members are considered vital for ensuring improved group or team performance.

6. Study 4: Energy Count and Organizational Health of an R&D System

The concept of ‘Energy Count’ has been adopted from Dhawan, Roy and Kumar (2002). This is based on the assumption that scientists working in an R&D organizational system use their mental skill more often compared to those personnel who are involved in routine though important tasks. Therefore, it is vital important for social scientists working on ‘organizational analysis’ to understand those factors and forces (both within and outside the organization) which activate or deplete the mental energy of the scientists.

Etzioni (1968) has used the energy concept while expounding he theme of human mobilization for purposeful collective social action. In his formulation, energy is expressed as a psychic and social resource. Human beings as members of a social system can be activated through reflected-upon experiences to commit themselves to a transcendental mission to bring about social change. Potential of collective human energy (termed as organizational energy) is the key to Etzioni’s conceptual map of social change. The energyissue thus could be approached as a diagnostic tool for social system analysis.

Dhawan et al. (2002), in their study, have employed a people-oriented approach called organizational energy to develop a simple process for diagnosing the level of satisfaction of scientists working in R&D laboratories. The conclusions of the study were based upon an empirical study, the sampling framework and the sample process being the same as that described for Study 3. Psychic energy as reflected in different work activities in an organization is mani

Table 2. Step-wise Regression of Overall Work Group Satisfaction

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Significant factor</th>
<th>R² = 0.55</th>
<th>R² change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab-1</td>
<td>Information sharing</td>
<td>0.62</td>
<td>0.14</td>
</tr>
<tr>
<td>(N = 64)</td>
<td>Group adaptability</td>
<td>0.76</td>
<td>0.14</td>
</tr>
<tr>
<td>Lab-2</td>
<td>Making group decisions</td>
<td>0.84</td>
<td>0.08</td>
</tr>
<tr>
<td>(N = 62)</td>
<td>Confidence and trust</td>
<td>0.49</td>
<td>0.12</td>
</tr>
<tr>
<td>Lab-3</td>
<td>Group adaptability</td>
<td>0.61</td>
<td>0.12</td>
</tr>
<tr>
<td>(N = 82)</td>
<td>Making group decisions</td>
<td>0.70</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Confidence and trust</td>
<td>0.62</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>Coordination</td>
<td>0.79</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>Making group decisions</td>
<td>0.86</td>
<td>0.07</td>
</tr>
</tbody>
</table>
fested in energy generating and energy draining activities that can be reduced to an energy count. Energy generating activities are those activities that generate more energy in the work system, motivating the scientists further to carry out their assignments. Energy draining activities are those activities that drain out energy from the work system, and consequently, completing such tasks thus seems to be a drag on the scientists. The energy count is defined as the ratio of energy generating score to the energy draining score. Clearly, when the energy count is high, the scientists are more satisfied with their work system.

7. The System Dynamics Approach

System dynamics (Forrester, 1976; Coyle, 1996, 1979; Wolstenholme, 1990) is a methodology that provides a paradigm with which complex, dynamic and non-linear interactions in social system can be understood and analyzed and new structures and policies can be developed to obtain desired improved behaviour of systems. It allows one to use a systems approach in visualizing and solving a problem holistically. The epistemological underpinnings of the system dynamics paradigm are the following (Mohapatra and Mandal, 1994):

- It is problem-oriented.
- It takes a holistic view of the problem
- The central focus is on policy.
- It considers long time frames.
- Model boundary includes factors that are considered important in the problem context.
- It emphasizes development of causal relationships.

System dynamics has been proposed here as the methodology for structural and policy analysis of the R&D organizational system in CSIR, India, because of its many desirable characteristics such as generality, ease of communication, ability to explicitly represent physical flows and inherent capability to model nonlinearities and produce model behaviour in time (Forrester, 1976; Mohapatra, Mandal and Bora, 1994). System dynamics blends the principles of traditional management and cybernetics to construct the structure of model and then uses computer simulation to generate the dynamic behaviour (Forrester, Mass and Ryan, 1976).

Jacobsen (1984) has commented that there are a number of features of system dynamics methodology which make it suitable for testing social theory. First, it is possible to handle many variables simultaneously, and study their fluctuations over time. Secondly, we can take account of multiple feedback loops in the system under investigation and study their mutual influences, again, over time. Furthermore, we do not have to stick to linear hypothesis, and can readily model any nonlinear relationships posited by the theory. Roy, Jain and Mohapatra (2001) have applied this methodology for forecasting and simulating scientific manpower under various policy regimes for a CSIR laboratory and Roy, Sharma and Bhushan (2005) have used it for probing the growth of business process outsourcing activities in India.

8. The System Dynamics Model

A system dynamics model of the overall R&D organizational system, considering primarily the case of CSIR, India (possibly similar to such systems in other countries), has been developed and the model stock-flow diagram is presented in Figure 3.

The model stock-flow diagram can be explained as follows. The combined R&D effectiveness index results in an effectiveness pressure that in turn affects the fraction of the total number of papers/ reports/ patents/ processes/ know-how developed per year. This fraction is also determined by a pressure from overall coordination - both intra and inter-departmental (into which significant contributions are due to integration and interdependence among the departments/areas), a pressure from overall motivational level within the organization and a multiplier constant alpha. This fraction of completed work per unit time affects R&D performance rate. The R&D performance rate is smoothed or averaged which, coupled with project proposed rate, leads to project selection/rejection rate after a delay. A multiplier, depending upon the merit of the incoming project proposals, gives us the project selection rate. Then, after a series of first-order delays we have the project start rate and project completion/abandonment rate. The level variables are projects in pipeline and projects in progress respectively. The total number of projects in progress also determines the total number of papers/ reports/ patents/ processes/ know-how under progress along with an output multiplier. Both the project start delay time and the project completion/ abandonment delay time are affected by the respective level variables apart from a resource constraint factor (both financial and material) multiplier as well as the size of the organization. A weighted average of these two delay times determines the overall motivational level input flow rate. This stock-flow diagram may be translated into a set of equations that can be simulated by using any standard system dynamics software, using real life data enabling us to analyze the behavior of such a system under various organizational policy regimes.
9. Conclusions

The human activities and relationships that exist in an R&D organization form a soft system within the technology based structured R&D organization. This system is largely unstructured and is beset with problems of measurement. Probing such a system using a system dynamics framework that allows for analyzing complex, dynamic and non-linear interactions in social systems, therefore, requires conducting a series of sub-studies to look into different dimensions of the overall human activity system that could then integrated into a coherent whole of the R&D organizational system. This has been precisely the aim of the present exercise.

A system dynamics model of the overall R&D organizational system has been developed by the authors. It is based on the results and formulations of the four studies described in the paper and an understanding of the overall operational features of such a system being an integral part of it for over two decades. However, this is only the first stage as following the conceptualization of the model, a big step it its own right, real numbers need to be put in the model through a structured data collection exercise for it to be simulated to generate useful insights into the functioning of such R&D organizational systems under various policy regimes.
References


