Chapter 5

EXECUTION PHASE

“Plans are only good intentions unless they immediately degenerate into hard work.”

- Peter Drucker
Chapter 5

EXECUTION PHASE

5.1. INTRODUCTION TO EXECUTION PHASE OF A PROJECT

The execution phase will give the project its actual shape to create the necessary end product or service. When the project plan has been completed and the development work is about to start as per the operating timetable, the project manager will keep more focus on the allocation of right resources to the tasks in hand and check their availability and functions. After allocating different resources to different tasks, the project manager will check whether the project is progressing as per schedule, and if any deviations are observed, the project manager will apply appropriate control measures to bring the project right into the track. Other activities like subcontracting some works to outside developers, procuring required equipment and tools, etc. should also be performed properly based on requirements of the project without disturbing the following scheduled activities. In addition, the quality of the project in each unit or module at every stage should be assessed, improved and managed continuously. At every step, the project manager and team members should check the outcomes with the project plan and make sure that the project is being executed as per plan.

In view of the above, the different activities to be managed in the execution phase of a project are:

- Resources management
- Management of procurement/contract
- Project monitoring
- Project Control.
5.2. RESOURCE MANAGEMENT

A project is done by a finite number of people using different tools, technologies, skills, knowledge, experience, etc. A resource may be any item or person required to execute the project work. There are different categories of resources - labour, equipment, materials, space, services, time and money. Labour resources consist of project development team members; equipment includes computing and office equipment that are operated; materials are items that are consumed; space is the space required to accommodate the people, equipment and materials; and services are special services like transport, telecommunications services, etc. Any project or any of its tasks needs some time duration for its completion and also need money to spend on the resources and other activities. The human effort per task measured in terms of time units like person-hours/days/weeks/months is converted to the currency based on the labour rates. The labour rates include both the highest-paid employees and lowest-paid employees, together with the manager and clerical support.

Resource management deals with management of resources, which includes allotment of resources, their optimum use, control, etc. Based on the availability and usage of resources and requirements of the tasks, appropriate resources will be allotted to the tasks of the project. Management of human resources will be another important activity in resource management. Hence, the system of 'Resource management' consists of two important activities - (i) 'Resource allocation' (both human and non-human resources) and (ii) 'Human Resource loading and leveling'. All the system dynamics modeling and simulation activities have been carried out separately for each of these two sub-systems in the system of resource management.

Two real-world case studies are hereby given to highlight the importance of resource management in projects.

Case study I: In the year 1998, APTS was directed by the A.P. State Government to install one server and two client computer systems at each of about 300 selected Mandal Revenue Offices in the first phase of computerization of mandal offices and then install the required operating, database and office software systems and also the specially developed software
packages like MPHS (Multi-Purpose Household Survey) and Payroll. That job was to be completed within a month on war footing basis. To do this marathon task, APTS exercised very hard and drafted a systematic plan. As per the plan, the hardware and software vendors were asked to supply and install their systems directly at respective offices in different districts. The staff of APTS and contractors (who developed MPHS application along with APTS) were divided into groups and these groups were directed to those places where the installation of machines was going on to continue the computerization activity to work along with the staff of vendors. Along with installation, the activity of training to the system users of revenue offices1 was also included in the project. Wherever the number of team members was not sufficient or so many unexpected problems like problems of hardware or software or integration of both or inefficient staff occurred, APTS after reviewing the progress of work, sent required number of people to adjust the resource and skill requirements. This was done based on the reserve staff, APTS was holding or relieving some team members from the ongoing in-house projects. Such resource leveling was successfully done in some places and moderately in other places.

Low-skill level of some people resulted in extension of effort and addition of extra effort. This type of situations forced APTS to either guide and enlighten those people over phone or replace those inefficient people by better-skilled people or transferring some well-performing people from the places where the works were in very good progress.

When some staff members performed extremely well and completed their jobs ahead of the schedule, they were directed to other places where the work was running very slowly due to various problems. But the activity of sending extra people or experts to the needy places became a challenge for APTS and demanded the necessity of maintaining reserve staff. To avoid such problem, APTS opened an on-line help over phone to those people who needed guidance and hints for smooth running of their tasks. Thus APTS could manage the resources successfully.

1 Each district is divided into some revenue divisions and each revenue division is divided into some mandal revenue offices which are headed by Mandal Revenue Officers (MROs).
Case study II: A module of a project done by MCSB has been taken as another case study. The project is related to development of a product's performance appraisal system for the customers. Two people have been kept on this module, but the two people were available to the module for only 60% of their total availability time, by spending the remaining 40% of their availability time on other works like debugging other modules already developed by them or by others. The estimated completion time was 3 months. Due to the constraints on the resources and their availability time, the project was delayed maximum by 2 months, i.e., total duration becoming 5 months.

5.2.1. RESOURCE ALLOCATION

'Resource allocation' means allocation of physical resources to different activities of the project. Factors like availability of resources in the organization and their availability percentage to the proposed project activity influence the resource allocation process and the on-time project development. When an organization is having a project in hand, the project manager will allocate the people to the different tasks taking into account the matching between the skill requirements of the task and the skills and experience of the person(s). Similarly, based on the requirements, other resources like machines, tools, software, stationery, etc. will be gathered and assigned to the team members.

Historically, majority of IT organizations have had major difficulties in recruiting and retaining qualified and experienced IT staff. The IT staff always looks for career development, technical challenges, compensation, and promotion. 20-40% of the project staff may change over during the course of project (Murch 2001). When someone leaves a company to join elsewhere, the cost of replacing that person will be prohibitively expensive. It is expensive not only in terms of monetary costs, but also in terms of cost of knowledge and experience that the person had acquired and contributed in the organization. Shortage of qualified staff in IT organizations makes them experience major loss of market share and opportunities to compete in the dynamic market environment and unable to develop and implement new and innovative systems in time and ultimately the organizations sink into
losses. The same problem has been experienced and expressed by most of the organizations surveyed.

In APTS, when the actual project development is planned to start, the project manager would assign the different activities to project leaders and programmers. A meeting would be convened and jobs would be assigned and an official order containing all those details will be issued to all the concerned project team members. The team members who have studied and analysed the feasibility of taking up the project might not participate in the project development work, because APTS maintains different groups for different activities. If a project needs contribution of any one of the feasibility group members or members of other groups or projects, depending on their relative availability factor the project manager allocates those human resources to different tasks.

In NHCL, the project manager had the power to hire the service of outside people and get the project done in time along with the existing in-house team members. The availability of the existing people and their availability time to the particular project would be studied. Based on the effort to be put on each and every task, resource allocation will be done to complete the tasks as per schedule. In this organization, in many cases, the people working on a particular project would not be disturbed or diverted to work on other project(s) simultaneously.

All the surveyed organizations provided the required hardware, tools, stationery and other necessary facilities to the project team. Some specific conditions were observed in some organizations, like restricted usage of some valuable software packages like software testing/designing tools, adjustment with whatever software available in the organization, waiting still for the software ordered for purchase, etc. To avoid purchasing of many copies of some expensive software packages, some organizations instructed the project teams to use the computer systems having such software during the assigned limited time-slots or free-time. Therefore, all those non-human resources should be properly and reasonably allotted to the team members based on the requirements to avoid delays so as to run the project work smoothly.
Following the above discussions, all the salient variables that influence the activity of 'Resource allocation' in the sub-system of 'Resource management' have been identified and listed in Table 5.2.1.

| Table 5.2.1. List of salient variables in the system of 'Resource allocation' |
|-----------------------------|-----------------------------|
| 1.  Resources               | 2.  Availability percentage|
| 3.  Resources availability rate | 4.  Resources requirement rate |
| 5.  Effort                  | 6.  Activity delay rate     |
| 7.  Project delay           |

5.2.1.1. Basic SD feedback loops in 'Resource allocation' activity

(a) When enough resources exist, the rate of availability of resources for an activity will be more and the resource requirement rate will be reduced. Hence the causal link connecting the variable 'Resources' to the variable 'Resources availability rate' has been treated as a positive link and the link between the variables 'Resources' and 'Resource requirement rate' has been treated as a negative link. When the rate of availability of resources is increased, resource allocation process will be carried out easily and hence the causal link from 'Resources availability rate' to 'Resource allocation' will be positive. Improvement in resource allocation will reduce the rate of requiring resources and hence the causal link between the variables 'Resource allocation' and 'Resource requirement rate' will be a negative link. The feedback loop formed by these four causal links becomes a positive loop, because of the presence of even number (two) of negative links.

(b) When the effort increases, there will be chances for delay in performing the activity and demand for more resource allocation arises to perform the job satisfactorily. Hence the causal links connecting the variable 'Effort' with the two variables 'Activity delay rate' and
'Resource allocation' have been treated as positive links. When the resource allocation is improved, the delay in the activity will be slowed down and hence the causal link between the variables 'Resource allocation' and 'Activity delay rate' will be negative. The feedback loop formed by these three causal links will be a negative loop because of the presence of one negative causal link.

(c) When the percentage of availability of resource(s) to the activity increases, the resource availability rate will be improved and delay in the activity will be reduced. Based on this, the causal link connecting the variable 'Availability percentage' with 'Resource availability rate' has been treated as a positive link and that connecting with 'Activity delay rate' has been treated as a negative link. The causal link between the variables 'Resource availability rate' and 'Resource allocation' is a positive link and the two links connecting the variable 'Effort' with the variables 'Resource allocation' and 'Activity delay rate' are positive links. The feedback loop formed by these five causal links will become a negative loop because of the presence of one negative causal link.

(d) The causal links connecting the variable 'Resources allocation' with the two variables 'Resources requirement rate' and 'Activity delay rate' are negative links. When the requirement of resources increases, it delays the completion of activity and hence the causal link between the two variables, 'Resources requirement rate' and 'Activity delay rate' will be positive. The feedback loop formed by these three causal links will be a positive loop because of the presence of even (two) number of negative causal links.

All the four feedback loops are shown in the figure, Fig. 5.2.1.1.
5.2.1.2. Causal loop model of 'Resource allocation'

The rate of increase of delay in an activity affects the total project and results in the growth of delay in the project. Hence the causal link connecting the two variables, 'Activity delay rate' and 'Project delay' will be a positive link. With the help of this causal link and the four feedback loops described earlier, the causal loop model has been developed for the system of 'Resource allocation' and is shown in the figure, Fig. 5.2.1.2.
5.2.1.3. Stock and flow model of the system of 'Resource allocation'

In the causal loop model of 'Resource allocation', the three variables, 'Resource availability rate', 'Resource requirement rate' and 'Activity delay rate' have been treated as the rate variables, whereas the two variables 'Resource allocation' and 'Project delay' have been treated as level (or stock) variables. Then the total stock and flow model for the system of 'Resource allocation' has been developed and is shown in the figure, Fig. 5.2.1.3.
5.2.1.4. Modeling equations for the system of 'Resource allocation'

Based on the data collected from the case study II related to the organization, MCSB systems, the duration of the project has been assumed as 5 months, number of resources as 2, effort as 3 (that is, 3 days or weeks) and availability percentage of resource as 60%, i.e., 0.6. Hence the initial time is 0 month and the final time is 5 months and the time step has been taken as 0.25 month. All the modeling equations are listed in Table 5.2.1.4.

Resource availability rate has been equated to the product of the two variables, 'Resources', and 'Availability percentage' and also a numerical value of 60. The stock variable 'Resource allocation' is equated to the integration of the product of resource availability rate and effort divided by 1000 with an initial value of 1. IF...THEN...ELSE condition has been assigned to the variable 'Resource requirement rate': if the resource allocation is greater than resources, then the value of 'Resource requirement rate' will be the product of a numerical value of 50 and the difference between 'Resource allocation' and 'Resources'. 
otherwise (that means, if that condition is not true) the value of ‘Resource requirement rate’ will be equal to 100 divided by the sum of ‘Resources’ and ‘Resource allocation’. Similarly, another IF...THEN...ELSE condition has been assigned to the variable ‘Activity delay rate’; if ‘Availability percentage’ is greater than or equal to 1, that means, the resources are fully available to the project, then the activity delay rate will be 0 (zero), otherwise the activity delay rate will be equal to the product of ‘Resource requirement rate’ and ‘Effort’ divided by 1 plus the product of ‘Resource allocation’ and ‘Availability percentage’. The second stock variable ‘Project delay’ is equated to the integration of the difference between the ratio of activity delay rate to 100 and a numerical value of 0.1 with the initial value assumed as 0 (zero).

Table 5.2.1.4. SD modeling equations of ‘Resource allocation’

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>INITIAL TIME = 0 (The initial time for the simulation).</td>
</tr>
<tr>
<td>(B)</td>
<td>FINAL TIME = 5 (The final time for the simulation).</td>
</tr>
<tr>
<td>(C)</td>
<td>TIME STEP = 0.25 (The time step for the simulation).</td>
</tr>
<tr>
<td>(D)</td>
<td>SAVEPER = TIME STEP (The frequency with which output is stored).</td>
</tr>
<tr>
<td>(1)</td>
<td>Effort = 3.</td>
</tr>
<tr>
<td>(2)</td>
<td>Resources = 2.</td>
</tr>
<tr>
<td>(3)</td>
<td>Availability percentage = 0.6.</td>
</tr>
<tr>
<td>(4)</td>
<td>Resource availability rate = 60<em>Resources</em>Availability percentage.</td>
</tr>
<tr>
<td>(5)</td>
<td>Resource allocation = INTEG (Resource availability rate*Effort/1000, 1).</td>
</tr>
<tr>
<td>(6)</td>
<td>Resource requirement rate = IF THEN ELSE (Resource allocation &gt; Resources, (Resource allocation - Resources)*50 + 100/(Resources + Resource allocation)).</td>
</tr>
<tr>
<td>(7)</td>
<td>Activity delay rate = IF THEN ELSE (Availability percentage&gt;=1 , 0 , Resource requirement rate<em>Effort/(1+Resource allocation</em>Availability percentage)).</td>
</tr>
<tr>
<td>(8)</td>
<td>Project delay = INTEG (Activity delay rate/100 · 0.1, 0).</td>
</tr>
</tbody>
</table>
5.2.1.5. Simulation analysis of the system of ‘Resource allocation’

The stock and flow model along with the modeling equations has been simulated. From the initial run of simulation, a growth behaviour is observed in the variables ‘Resource allocation’ and ‘Project delay’, whereas decay behaviour observed in the variables ‘Resources requirement rate’ and ‘activity delay rate’, with a steady behaviour in the variable ‘Resource availability rate’ maintaining at a value of about 72. The variable ‘Resource allocation’ started at 1 and finally approached a value 2; ‘Resource requirement rate’ dropped from a value of about 33 to about 25, then dropped steeply to zero (0) and then slightly raised touching a final value of about 3; ‘Project delay’ starting from 0 approached finally a value of about 1.8. The variable ‘Activity delay rate’ followed the same pattern of behaviour of the variable ‘Resource requirement rate’ but with different values. It started dropping from a value of about 65 (that is, 65%) to a value of nearly 35, from there dropped steeply to zero and then raised and ended at a value near 5. In the case of projects, it has been observed from the survey reports that due to constraints on resources and their availability to perform a task that demands more effort, naturally there will be some delay in the concerned activities and the overall project and such delays can be reduced with the help of good allocation of resources.

While the activity delay rate drops from 65% to a value of about 35%, the project delay has grown to nearly 2 that means, nearly 2 months. This result is validating the delay of about 2 months as experienced by MCSB in the case study II. The resource allocation remained between 1 and 2, which means, 2 resources have been assigned to the job, which is found true from the case study.

Hence the simulation results tally with the feedback of the surveyed organizations.

The patterns of behaviour resulted from the simulation of the system of ‘Resource allocation’ are shown in the figure, Fig. 5.2.1.5.
5.2.1.6. Sensitivity analysis results of the system ‘Resource allocation’
Sensitivity analysis has been performed by changing the values of one of the three variables, ‘Effort’, ‘Resources’ and ‘Availability percentage’. All the sensitivity analysis results are shown in the figures, Fig. 5.2.1.6.(i) to (iii). In each figure, the graph I (red colour)
represents the result of initial run of simulation, whereas the graph II (blue colour) represents the sensitivity analysis result.

(i) When the value of the variable ‘Effort’ is increased from 3 to 5, further growth is observed in the variable ‘Resource allocation’ whose final value approached 3 and no change observed in ‘Resource availability rate’. ‘Resource requirement rate’ started its slow decay from the same initial value of 3.3 to a value near 20 beyond half of the total run time and then suddenly dropped to zero, from where it picked up an exponential growth by finally reaching a higher value above 40. Project delay further increased to 2.5. ‘Activity delay rate’ started from a higher value of 100 and dropped to zero beyond half of the total run-time and then exponentially grew to a final value of 75. These results say that when the effort to be put up for an activity increases, there will be more demand for the resource allocation and this situation delays the project more. Since the number of already allocated resources and their availability percentage are constant, the activity delay will be high at the start, but decays later on. Similar behaviour is observed in the case of activity delay rate.

Due to constraints on usage of human resources, the project managers of MCSB tried to avoid extension of effort, demand for more resources and delays in the activities and the total project as well.
(ii) When the value of 'Resources' is increased from 2 to 3, resource requirement rate started its decay from a value of about 25 (instead of 35 as observed in initial run), almost parallel to the result of initial run till 90% of the total run time and finally touched a value just below 20. The same pattern of behaviour is observed in the case of 'Activity
delay rate', but with different values. Project delay maintained its growth, but less than the growth as observed in the result of initial run.

In APTS, it was observed in some projects like Budget data on disk, MPHS (Multi-Purpose Household Survey), Computerization of offices of MROs, etc. that skilled people and some other additional staff were deputed to some urgent activities to avoid delays in those activities and the total project. In the case of MCSB systems, it was not possible to get additional resources to the delayed projects due to severe scarcity of human resources and in such situations and the managers tried to convince and request the users to extend the project completion time, if necessary.

Fig. 5.2.1.6 (ii). Sensitivity analysis of 'Resource allocation'

<table>
<thead>
<tr>
<th>Resource allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resource availability rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
</tr>
<tr>
<td>165</td>
</tr>
<tr>
<td>130</td>
</tr>
<tr>
<td>95</td>
</tr>
<tr>
<td>60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resource requirement rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

Contd......
(iii) When the value of the variable 'Availability percentage' is increased from 0.6 to 0.8, resource requirement rate dropped almost in the same pattern as observed in the result of initial run up to 70% of the total run time, from where it steeply dropped to zero and then picked up exponential growth by finally touching a value just above 20, much higher than the value as observed in the initial simulation run. Similar pattern of behaviour is observed in the case of 'Activity delay rate'. Both 'Resource requirement rate' and 'Activity delay rate' started at lower values and ended at higher values when compared with the results of their initial runs. Project delay continued with growth behaviour, but less than that as observed in the result of initial run, by finally touching a value just above 1. Hence, the decay in project delay has been much slowed down when compared with the result of initial run.

In MCSB, when a team member relieves from other additional works like debugging (correcting the computer programs), testing, etc., then that person spends the maximum time (100%) to the project under development. Such instances led MCSB to overcome delays in the activities and the total project as well.
Fig. 5.2.1.6 (iii). Sensitivity analysis results for ‘Resource allocation’

- Resource allocation
- Resource availability rate
- Resource requirement rate
- Project delay
- Activity delay rate

Time (Month)
5.2.2. HUMAN RESOURCE LOADING AND LEVELING

Resource loading describes the amount of individual resources a scheduled task requires and it gives a general understanding of the demands a task or the project will make on a firm's resources. When the resource requirement exceeds the available resources, that situation is called 'resource overload'. This delays some activities leading to delay in the whole project. When the resource requirement is lower than the available resources, it is called 'resource underload'. In the case of human resources allocation, apart from these factors there are many other influencing factors other than these like risk involved, skill level and training of the staff, team building, etc.

'Resource leveling' (or 'Resource smoothing') is the process of controlling daily resource requirements of different tasks and smoothing out their use over the course of the project. It levels the situations of resource overload or resource unload by relieving or adding required number of resources and creates a smoother distribution of resource usage. Resource leveling leads to both managerial and important cost implications. By this, the associated costs tend to be leveled and employment will also be leveled throughout the project. Sometimes, the resource leveling can be done by distributing the resources relieved from other tasks on to the slowly moving tasks.

When resource leveling is not properly done, it leads to delays in the activities and thereby affecting other ones and totally delaying the project. DeMarco (1982) argued that the extension of development schedule severely affects not only the project and its team, but also the organization. It is also reported that when a project is initiated, the initial estimates should be refined throughout the project verifying each time the likelihood to meet the established deadline. Jigeesh et al (2004) developed an expert system for human resource leveling in IT projects without changing the development schedules and moving the activities. They derived many fuzzy logic rules among four variables - the project effort, skills of the people, risk level and the ultimate resource leveling. Their work considered the problem of balancing the human resources required to perform the assigned task within the
development schedule taking into view the affects of varying skills of the persons and the possible risks in performing the task.

According to Murch (2001), project managers rely on good and qualified staff to help ensure a project's success. Good talent has always been hard to find but, in today's IT market, it is becoming nearly impossible to find the right people to do the work. Even when they are found, they can be difficult to keep. In government organizations, to get a good technical person having particular software skills is very difficult, because of many constraints like meager salary, lengthy selection procedures and policies when compared with private companies. To get approval to recruit people, the organization has to get orders from different levels of hierarchy. But in private organizations, this activity will be done very fast as they are purely project oriented and commercial.

It was observed with some software developers like R.K. Group of Companies, that the technical people who have completed their task in time or before scheduled time would be distributed among the slowly moving tasks to speed up the total project. The slowness in activities may be due to low skill-level of the allotted personnel or due to complexity in the application or due to lack of understanding of the requirements. In this case, the skill level is found as an important factor playing a major role in performing the tasks as per schedule and also positively influencing the resource leveling process when the resource allocation is not properly done and risk level is becoming high.

In view of the above discussions, the salient variables that influence the activity of 'Human resource loading and leveling' have been identified and listed in Table 5.2.2.
### Table 5.2.2. List of salient variables in the system of 'Human resource loading and leveling'

<table>
<thead>
<tr>
<th>Salient variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Resources</td>
</tr>
<tr>
<td>2. Effort</td>
</tr>
<tr>
<td>3. Skill level</td>
</tr>
<tr>
<td>4. Risk level</td>
</tr>
<tr>
<td>5. Resources adding rate</td>
</tr>
<tr>
<td>6. Effort adding rate</td>
</tr>
<tr>
<td>7. Extra effort</td>
</tr>
<tr>
<td>8. Human Resource loading</td>
</tr>
<tr>
<td>9. Human resource leveling</td>
</tr>
</tbody>
</table>

#### 5.2.2.1. Basic SD feedback loops of 'Human resource loading and leveling' activity

(a) When available resources are more, the leveling of resources among the project activities will be done satisfactorily and the rate of adding resources to the needy activities will be done effectively. Hence the causal links from the variable 'Resources' to the two variables, 'Resources adding rate' and 'Human resource leveling' have been treated as positive links. When loading of human resources is effectively done, there will be less need for more resources and hence the causal link connecting 'Human Resource loading' to 'Resources adding rate' will be negative. Resource leveling comes into picture when there is overload or underload of resources to an activity as per the resource requirements. If the human resource loading is reduced, there will be imminent need to level the existing resources among the project activities. Hence the causal link connecting the variable 'Human Resource loading' with 'Human resource leveling' will be a negative link. The feedback loop formed by these causal links will become a positive loop because of the presence of two (even number) negative causal links.

(b) When there is a lot of risk involved or expected in an activity, there will be extra effort to be put to perform the task by avoiding or mitigating the risk and to do this extra work,
adding sufficient number of additional resources to the activity will be one of the solutions. Hence the causal links connecting the variable ‘Risk value’ to the two variables, ‘Resources adding rate’ and ‘Effort adding rate’ have been treated as positive links. When the skill level of the human resources increases, the rate of adding further resources will be reduced and hence the causal link connecting the variables ‘Skill level’ and ‘Resources adding rate’ will be a negative link. In addition, increase in skill level of the resources reduces the rate of adding extra effort and hence the cause link between the two variables ‘Skill level’ and ‘Effort adding rate’ has been treated as a negative link. The feedback loop formed by these four links will be positive because the number of negative links present is even (two).

(c) The causal links connecting the variable ‘Skill level’ to the two variables ‘Resources adding rate’ and ‘Effort adding rate’ are negative links. When the effort to be put on an activity increases, it leads to addition of extra effort and demands addition of extra resources. Hence the causal links connecting the variable ‘Effort’ to the variables ‘Resources adding rate’ and ‘Effort adding rate’ will be positive links. The feedback loop formed by the four causal links will be a positive loop, because of the even (two) number of negative links.

(d) The causal links connecting the variable ‘Effort’ to the two variables ‘Resources adding rate’ and ‘Effort adding rate’ are positive links. The increase in the rate of adding effort leads to the growth of extra effort to be put up by the resources and hence the causal link between the variables ‘Effort adding rate’ and ‘Extra effort’ will be a positive link. The causal link from the variable ‘Human Resource loading’ to ‘Resources adding rate’ is negative. Increase in extra effort demands loading of more human resources and hence the causal link between the variables ‘Extra effort’ and ‘Human Resource loading’ will be a positive link. Because of the presence of one negative causal link, the feedback loop formed by all these five causal links will be a negative loop.

(e) The causal link between the two variables, ‘Extra effort’ and ‘Human Resource loading’ is a positive link and the causal link between the variables ‘Human Resource loading’ and ‘Human resource leveling’ is a negative link. Increase in the extra effort to be put on the activity demands more leveling of human resources and hence the causal link between the
variables ‘Extra effort’ and ‘Human resource leveling’ has been treated as a positive link. The feedback loop formed by these three causal links will become a negative loop because of the presence of one negative link.

All the five feedback loops are shown in the figure, Fig. 5.2.2.1.

Fig. 5.2.2.1. **SD feedback loops in the system of ‘Human resource loading and leveling’**

![Feedback loops](image)

5.2.2.2. Causal loop model of the system of ‘Human resource loading and leveling’

Based on the inter-relationships between the different variables and their influence on each other as described in the feedback loops, the causal loop model has been developed for the system of ‘Human resource loading and leveling’ and is shown in the figure, Fig. 5.2.2.2.
5.2.2.3. *Stock and flow model of the system of 'Human resource loading and leveling'*

The stock and flow model has been developed based on the causal loop model and is shown in the figure, Fig. 5.2.2.3. The variables 'Resources adding rate' and 'Human resource leveling' have been treated as rate variables and the variable 'Human resource loading' as a level (or stock) variable. The variable 'Effort adding rate' has been treated as another rate variable and the variable 'Extra effort' as another level (or stock) variable to represent the extra effort to be put up on the project and be filled due to changes in the respective influencing variables like risk value, skill level, etc.
5.2.2.4. Modeling equations for the system of ‘Human resource loading and leveling’

The various system dynamics modeling equations framed for the system of ‘Human resource loading and leveling’ are given in Table 5.2.2.4. Like the system of ‘Resource allocation’, the duration for the system of ‘Human resource loading and leveling’ has also been treated as 5 months as in the case of ‘Resource allocation’. Time step for the simulation has been taken as 0.0625 month.

Following the data of the case study II as mentioned in the introduction of the topic of resource management, the variable ‘Effort’ is assigned a value of 3 and the variable ‘Resources’ assigned a value of 1. The variable ‘Skill level’ has been assigned a value of 1 and ‘Risk value’ a value of 5 by assuming that the team member is having appropriate skills and there is some risk in the activity but at minimum level. The variable ‘Effort adding rate’ has been equated to the product of effort and the logarithm of ‘Risk value’ divided by ‘Skill value’. 
level' and then subtracting 1. The level variable 'Extra effort' has been equated to the integration of 'Effort adding rate' divided by 10 starting from an initial value of 0. A lengthy equation (7) comprising of the variables 'Resources', 'Risk value', 'Effort', 'Skill level' and 'Human Resource loading' has been assigned to the variable 'Resources adding rate'. Another level variable 'Human Resource loading' is equated to the integration of the product of 'Resources adding rate' and 'Extra effort' divided by 300 starting from an initial value of 0. Finally, the variable 'Human resource leveling' is assigned with another lengthy expression (9) composed of the variables 'Human Resource loading', 'Resources' and 'Extra effort'. In both the equations (7) and (9), IF THEN ELSE conditions have been used; the first element enclosed in the brackets is the actual condition, second one is the 'expression' that will be executed if the condition is true and the third element is the 'expression' that will be executed if the condition becomes false. In the condition element, OR and AND connectors have been used. 'OR' represents any one condition and 'AND' represents all conditions to be satisfied.

Table 5.2.2.4. SD modeling equations of the system of 'Human resource loading and leveling'

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>INITIAL TIME = 0 (The initial time for the simulation).</td>
</tr>
<tr>
<td>(B)</td>
<td>FINAL TIME = 5 (The final time for the simulation).</td>
</tr>
<tr>
<td>(C)</td>
<td>TIME STEP = 0.0625 (The time step for the simulation).</td>
</tr>
<tr>
<td>(D)</td>
<td>SAVEPER = TIME STEP (The frequency with which output is stored).</td>
</tr>
<tr>
<td>(1)</td>
<td>Effort = 3.</td>
</tr>
<tr>
<td>(2)</td>
<td>Resources = 2.</td>
</tr>
<tr>
<td>(3)</td>
<td>Skill level = 1.</td>
</tr>
<tr>
<td>(4)</td>
<td>Risk value = 5.</td>
</tr>
<tr>
<td>(5)</td>
<td>Effort adding rate = Effort*((LN(Risk value)/Skill level)-1).</td>
</tr>
<tr>
<td>(6)</td>
<td>Extra effort = INTEG (Effort adding rate/10.0)</td>
</tr>
<tr>
<td>(7)</td>
<td>Resources adding rate = IF THEN ELSE(Effort&lt;3 :OR: Risk value&lt;5 :OR: Skill level&gt;1, 0, Resources*LN(Risk value)*Effort/Skill level - Human Resource loading)*5.</td>
</tr>
</tbody>
</table>

(Contd....)
5.2.2.5. Simulation results of the system of 'Human resource loading and leveling'

The stock and flow model, after simulated with the assigned initial values and expressions of different variables, resulted different patterns of behaviour in the variables 'Human resource leveling', 'Extra effort', 'Human Resource loading' and 'Resources adding rate'. These results are shown in the figure, Fig. 5.2.2.5. Growth behaviour has been observed in the variables 'Human resource leveling', 'Extra effort' and 'Human Resource loading' and whereas slow decay behaviour observed in the variable 'Resources adding rate'. The final value of 'Extra effort' is close to 0.9, that of 'Human Resource loading' close to 0.35 and the final value of 'Human resource leveling' crossed 100. The variable 'Resources adding rate' started decaying slowly from a value of around 48 and ended around 47. The exponential growth behaviour of 'Human Resource loading' started at the middle of first quarter of the simulation time. 'Human resource leveling' had a steep growth from 0 to 60 and then maintained gradual growth behaviour by finally touching a value above 100 that mean 100%. Hence, the initial simulation run produced 100% human resource leveling, that is, the human resources are leveled satisfactorily.
5.2.2.5. Patterns of behaviour in 'Human resource loading and leveling'

Fig. 5.2.2.5. Patterns of behaviour in 'Human resource loading and leveling'

5.2.2.6. Sensitivity analysis of the system of 'Human resource loading and leveling'

Sensitivity analysis has been performed on the stock and flow model of the system of 'Human resource loading and leveling' by varying the values of the variables 'Skill level', 'Effort', 'Risk value' and 'Resources' independently. All these results are graphically represented in the figures Fig. 5.2.2.6(i) to (iv). In each figure, graph I (red colour) represents the result of initial simulation run and whereas graph II (blue colour) represents the sensitivity analysis result.
(i) When the value of ‘Skill level’ is reduced from initial value of 1 to 0.75, that mean the skill level of the assigned human resources becomes low by 25%. Growth behaviour is observed in ‘Human resource leveling’, ‘Extra effort’ and ‘Human Resource loading’, whereas decay behaviour observed in the variable, ‘Resources adding rate’. Human resource leveling further increased and reached a final value of about 140, when compared with the result of initial run (100), extra effort increased to 1.7 when compared with the value of initial run (1), human resource loading increased to 0.85 instead of 0.35 as was observed in initial run and resources adding rate dropped down from a higher value of 65 to another higher value of 60 when compared to the drop-down from 48 to 47 as observed in the initial run. These results show that when the skill level of the resource is less, there will be more extra effort to be put up and this situation demands adding of more resources and their loading, ultimately leading to further leveling of the resources.

It has been observed from the surveys, especially from some IT organizations, that the skill-level of IT people cannot be satisfactorily estimated by the interview panel during recruitment. A project manager of QuickNet.Com expressed that he had problems with some overseas technical people that entered the company with fake experience, which was noticed later on while working on the real project assigned to them. Software programming skills mean not only knowing the programming languages, but also implementing the programming knowledge and generating the results that meet the application requirements. When any team member shows poor performance in using the tools while developing the allotted part of application, the project manage has to identify such people and try to keep some additional resources to avoid delays.

In some surveyed cases, it was also observed that the project manager requests experts to extend their over time on the tasks that are lagging behind the schedule due to poor skills of team members. The Human Resources departments of the companies surveyed in Malaysia regularly collect the performance reports of all the employees, assign the performance index to every one and use those indices for deciding the incentives, promotion, continuation, etc. of each and every employee.
(ii) After increasing the value of 'Effort' from its initial value of 3 to 5, similar patterns of behaviour, as were observed in the case of effect of decrease in skill level, repeated, that is, growth behaviour in the variables 'Human resource leveling', 'Extra effort' and 'Human Resource loading' and whereas decay behaviour in 'Resources adding rate'. The final values of 'Human resource leveling', 'Extra effort', and 'Human Resource loading' approached 125, 1.5, and 1 respectively, whereas the final value of 'Resources adding rate' dropped from 80 to 75 and these values are very higher than those of initial run. These results interpret that when there is more effort to be put up, there will be
more extra work to be performed by the project team and this situation demands more addition of resources and their loading and leveling.

From the surveys, it was observed that increase in effort was smoothened either by allotting additional resources in case of availability or by making the existing resources to work extra hours. In either case, there would be proper loading and leveling of resources and their time.

*Fig. 5.2.2.6(ii). Sensitivity analysis of ‘Human resource loading and leveling’*

[Graph showing sensitivity analysis]
(iii) When 'Risk value' is increased from 5 to 10, that is, doubled, extra effort and human resource loading reached their highest values of 2 and above 1 respectively. Human resource leveling also touched a higher value, close to 1.50. The 'Resources adding rate' started from a value near 70 and dropped to a value below 65. This observation interprets that when there is more risk, there will be more extra effort to be put up to safeguard the task or project from such risk and this leads to requirement of more resources and their proper loading and leveling.

Fig. 5.2.2.6(iii) Sensitivity analysis of 'Human resource loading and leveling'
(iv) When the value of ‘Resources’ is increased from 2 to 3, the variable, ‘Human resource leveling’ experienced enormous growth crossing a value of 150, whereas no change is observed in the growth behaviour of ‘Extra effort’ from its initial behaviour as observed during the initial simulation run. However, there is a slight growth observed in the behaviour of ‘Human Resource loading’ which reached a value of about 0.55 when compared with the value of 0.35 as observed in the initial simulation run. Resources adding rate dropped from a value of 72 to 70. From these results, it can be interpreted that the increase of resources leads to their immediate loading and this demands more leveling. As effort is the same, there will be no change in the extra effort to be put up.

Fig. 5.2.2.6(iv). Sensitivity analysis of ‘Human resource loading and leveling’
The above results say that human resource leveling will be high when an extra resource is added; extra effort and human resource loading will be high when there is more risk; and resources adding rate will be high when the effort to be put up increases. The surveys conducted in Malaysia reveal that due to constraints on recruiting and allocating resources, the project team is facing a lot of problems in the form of risks created to the projects or project tasks to complete them within time, and to compensate the resulting extra effort the existing staff were working overtime.

5.3. MANAGEMENT OF PROCUREMENT/CONTRACT

'Procurement' is the process of acquisition of goods or services that involves two parties, namely the customer who wants and the supplier who supplies, in a specific market environment. The project schedule integrates the procurement activity by listing the items or services to be procured. Large size procurement of goods or services requires both parties to undergo a contract by signing an agreement between the parties detailing the benefits and responsibilities for those concerned.

In organizations, the procurement may be for (i) already developed/manufactured tools/equipment/services, or (ii) tools or services to be developed from scratch specifically for a customer, or (iii) customization of already developed/manufactured tools or equipment or services for the specific usage of a customer, etc. When it is planned to procure some items useful for the project or to give a part of the project work to outside developers on subcontract basis, proposals are generally invited from the suppliers concerned. When procurement is on large-scale, organizations usually go for the process of tendering. When the procurement is a limited one, organizations usually invite proposals from different potential suppliers. The invitation of proposals or tender bids may be open (open to a particular global area) or restricted to some suppliers.

Management of procurement of product(s) or service(s) involves the activities of receiving proposals or bids from different suppliers, evaluating them, awarding the work order to the
best one, management of supply and installation of product or service and settlement of all financial commitments, etc. When the procurement is a bulk one, tender notification will be issued and the tender bids will be evaluated to select the best bidder to award the order. In most of the cases of bulk procurement, a contract containing all the terms and conditions relating to the details of supply of the product or development of service and the financial commitments may be signed between the two parties, that is, the user and the supplier. The contract thus signed should be managed to check from time to time the fulfillment of all requirements documented therein. Clients are able to get a minimum price by putting out the contract to competitive bid and advertising an invitation for bid that lists customer requirements and usually results in low bids (Gray and Larson 2003, Fraser 1995, Beveridge and Velton 1978).

APTS, with the encouragement of Andhra Pradesh State Government, advanced its IT services in a revolutionary manner from 1997, by signing Memoranda of Understanding (MoUs) with giant multinational companies like Microsoft, Oracle, UNIX, IBM, etc. and motivated all the State Government departments, Directorates and Corporations to streamline their workflow by complete computerization of their offices. The departments that were using old character-based applications developed on operating systems like Disk Operating System (DOS) were motivated to shift to graphic user interface (GUI) applications developed on operating systems like Microsoft Windows, which ensure robust features like user-friendliness, development of attractive screens, simultaneous usage and access of various screens, etc. This trend created a lot of pressure on APTS and to do that mountainous task, APTS recruited many technical people in different categories. As the work pressure became too high to be handled exclusively by the APTS staff, APTS sub-contracted some works to outside suppliers/developers. APTS procured different software/hardware products and their licenses at competitive rates from the multinational companies like Microsoft, Oracle, IBM, etc. under memoranda of understanding and added nominal service charges to supply the products to the needy government departments. In addition, APTS started the activity of sub-contracting some projects related to software application development, video conferencing, wide area networking (WAN), etc. to external potential developers on the basis of tendering process. Some big software projects like budget data on diak/web,
computerization of Directorate of School education, Commercial Taxes department, etc. were developed by outside developers.

To select the potential software suppliers or developers, APTS implemented strict evaluation process. APTS selected the vendors either through tendering process or by calling proposals from limited number of potential developers. Whether it may be a simple proposal or tender bid, it would be scrutinized and evaluated strictly taking into view the needs and requirements of the user. APTS followed the same method for the supply of hardware, computer stationery, office automation equipment, etc. for different government departments. Sometimes, APTS acted as an agent to negotiate with the developer/supplier to supply the required products/services to the user department.

To make the system of ‘Management of procurement/contract’ more clear and detailed, it has been further divided into two major activities, namely, (i) ‘Successful Procurement’ and (ii) ‘Effective Tender evaluation’ and each activity has been separately dealt for modeling and simulation.

As an addition to the present research work, a new and simple decision making method, named as, Bit Decision Making (BDM) method, using simple Boolean algebra has been proposed and developed to ease the tedious process of evaluation of tenders. This method along with an example of its application to evaluate IT tenders is given in detail as an additional topic within the topic of ‘Effective Tender evaluation’.

5.3.1. SUCCESSFUL PROCUREMENT
Before purchasing any item, it is advisable to go for a good vendor. Hence the reputation of a vendor plays some important role in procurement of goods; for example, authorized dealer of branded product(s) or a vendor who has a long history of selling quality products. To purchase any product, first the organization should be clear about the features and usefulness of the product and the vendor details all such things through a proposal. Whatever product the organization procures, it should fit to the requirements of the organization, it should be
reliable and be in good condition. Then only the organization feels that the procurement is done successfully. To check the usefulness, suitability and quality of a product to be procured, there should be some experts that are expected to have good skills to evaluate the product.

During procurement of product(s), both the organization and the vendor will look at clear settlement of all financial matters on both sides and delivery of product with the proposed features and within the scheduled time. When all these conditions are fulfilled, the contract between the buyer and the vendor is said to be well managed.

Based on the above discussion, the different salient variables that involve and influence the system of successful procurement have been identified and listed below in Table 5.3.1.

<table>
<thead>
<tr>
<th>Salient variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reputation of vendor</td>
</tr>
<tr>
<td>2. Clarity of proposal</td>
</tr>
<tr>
<td>3. Adaptability of product</td>
</tr>
<tr>
<td>4. Usefulness of product</td>
</tr>
<tr>
<td>5. Skills of evaluators</td>
</tr>
<tr>
<td>6. Financial settlements</td>
</tr>
<tr>
<td>7. Timely delivery</td>
</tr>
</tbody>
</table>

5.3.1.1. Basic SD feedback loops in the system of 'Successful Procurement'
(a) The more the skills of the evaluators, the more will be the success in procurement activity and the procurement activity rate. Hence the causal links connecting the variable 'Skills of evaluators' with the two variables 'Successful Procurement' and 'Procurement rate' have been treated as positive links. When the success in procurement is increased, the rate of procurement activity will also be increased and hence the causal link between the two variables, 'Successful Procurement' and 'Procurement rate' has been assigned positive sign. The feedback loop formed by these three positive causal links will also be positive.
The two causal links connecting the variable 'Skills of evaluators' with the variables 'Successful Procurement' and 'Procurement rate' are positive links. When the product is more adaptable, the user will feel more satisfaction with the usefulness of the. This tendency speeds up the procurement activity. Hence the two causal links connecting the variable 'Adaptability of product' with the two variables, namely, 'Procurement rate' and 'Usefulness of product' have been treated as positive links. The usefulness of the products also speeds up the rate of management of contract between the vendor and the user and hence the causal link between the variables 'Usefulness of product' and 'Contract management rate' has been treated as positive link. Improvement in the rate of management of contract increases the successfulness of procurement and hence the causal link connecting the variables 'Contract management rate' and 'Successful Procurement' becomes a positive link. The feedback loop formed by all these six positive causal links will be a positive loop.

The two positive feedback loops are given in the figure, Fig. 5.3.1.1.

**Fig. 5.3.1.1. SD feedback loops in the system of 'Successful Procurement'**

---

5.3.1.2. Causal loop model of 'Successful Procurement'
When the proposal of the vendor for a product or service is clear by including all the details of the product(s), price, etc., it helps the user to have good understanding and clear idea whether to procure the product(s) or not. Similarly, the reputation of vendor also plays an
important role to impress the user to buy the product or service from the vendor with confidence. Hence, the causal links from the two variables ‘Reputation of vendor’ and ‘Clarity of proposal’ connecting to the variable ‘Procurement rate’ have been treated as positive links.

Settlement of financial matters and delivery of product in time will improve the management of contract. Hence the causal links from the two variables ‘Financial settlements’ and ‘Timely delivery’ connecting to the variable ‘Contract management rate’ have been treated as positive links.

Using the above causal links and the two feedback loops explained earlier, the causal loop model for the system of ‘Successful procurement’ has been developed as given in the figure, Fig.5.3.1.2.

*Fig. 5.3.1.2. Causal loop model of ‘Successful Procurement’*
5.3.1.3. **Stock and flow model of the system of ‘Successful Procurement’**

To simulate the system of successful procurement, the variables ‘Procurement rate’ and ‘Contract management rate’ have been assumed as rate variables and the variable ‘Successful Procurement’ as a stock (level) variable. Remaining variable have been assumed as auxiliary variables. Based on these assumptions, from the causal loop model, a stock and flow model has been developed for the system of successful procurement, as shown in the figure, Fig. 5.3.1.3.

![Stock and Flow model of 'Successful Procurement'](image)

5.3.1.4. **Modeling equations for the system of ‘Successful Procurement’**

The duration of the activity of procurement has been assumed as 2 months and simulation run has been carried out with a time step of 0.125 month. The variables, ‘Reputation of vendor’, ‘Clarity of proposal’, ‘Adaptability of product’, ‘Skills of evaluators’, ‘Financial settlements’ and ‘Timely delivery’ have been initiated with a value of unity (1). The variable, ‘Usefulness of product’ has been equated to ‘Adaptability of product’. ‘Contract management rate’ has been equated to the product of ‘Usefulness of product’, ‘Financial settlements’, ‘Timely delivery’ and a numerical value of ‘100’.
The variable ‘Procurement rate’ has been equated to product of ‘Successful Procurement’, ‘Skills of evaluators’ and the sum of the variables ‘Adaptability of product’, ‘Clarity of proposal’ and ‘Reputation of vendor’. The variable, ‘Successful Procurement’ has been equated to the integration of the sum of ‘Procurement rate’ and the product of ‘Contract management rate’ and sum of ‘Skills of evaluators’, divided by 10, with an initial value of unity (1). All these modeling equations are given in Table 5.3.1.4.

Table 5.3.1.4. SD modeling equations of the system of ‘Successful Procurement’

(i) INITIAL TIME = 0 (The initial time for the simulation).
(ii) FINAL TIME = 2 The final time for the simulation.
(iii) TIME STEP = 0.125 (The time step for the simulation).
(iv) SAVEPER = TIME STEP (The frequency with which output is stored).

(1) Reputation of vendor = 1.
(2) Clarity of proposal = 1.
(3) Adaptability of product = 1.
(4) Usefulness of product = Adaptability of product.
(5) Skills of evaluators = 1.
(6) Financial settlements = 1.
(7) Timely delivery = 1.
(8) Contract management rate = Usefulness of product * Financial settlements * Timely delivery*100.
(9) Procurement rate = (Adaptability of product + Clarity of proposal + Reputation of vendor) * Successful Procurement * Skills of evaluators.
(10) Successful Procurement= INTEG ((Contract management rate * Skills of evaluators + Procurement rate)/10, 1).
5.3.1.5. Simulation results of the system of ‘Successful Procurement’

When the stock and flow model of the system of successful procurement is simulated, exponential growth behaviour is observed in the two variables, ‘Successful Procurement’ and ‘Procurement rate’ as shown in the figure, Fig. 5.3.1.5. The variable ‘Procurement rate’ started its growth from 0 and ended at nearly 80, whereas ‘Successful Procurement’ started at 0 and ended near 28.

Fig. 5.3.1.5. Patterns of growth behaviour in the system of ‘Successful Procurement’

5.3.1.6. Sensitivity analysis results of the system of ‘Successful Procurement’

When the stock and flow model of ‘Successful Procurement’ is undergone automatic simulations by varying the values of the different influencing variables, it has been observed that the four variables, namely, ‘Financial settlements’, ‘Timely delivery’, ‘Skills of evaluators’ and ‘Adaptability of product’ are showing higher influence when compared with the influence shown by varying other two variables, ‘Reputation of vendor’ and ‘Clarity of proposal’. Hence the model predicts that the usage and suitability of the product or service, the skills of the evaluators that evaluate such features of the product, financial settlements and timely delivery of the product or service will decide the success of the procurement.
This observation can be validated by usual experience in any procurement, particularly IT procurement. The results of the sensitive analysis are shown in the figures (i) to (vi) of Fig. 5.3.1.6. In each figure, graph I (red colour) represents the initial simulation result, whereas graph II (blue colour) represents the result of sensitivity analysis.

(i) When the value of the variable 'Adaptability of product' is increased from 1 to 1.2, a considerable improvement is observed in the growth behaviour of the two variables 'Procurement rate' (touching a final value near 110) and 'Successful Procurement' (with a final value just below 35), as shown in the figure, Fig.5.3.1.6(i). Generally the product procured should be adaptable to the requirements and use of the user firm and only then the procurement can be treated as successful and this speeds up procurement process further. Hence the sensitivity analysis result has been well validated by this fact.

In APTS, while computerizing the mandal revenue offices, for client-server software application, initially DB2 database software licenses were taken from IBM and installed in the computer systems. After about two months, when it was observed at different locations that the software applications were not properly running, the project team started analysis of the problems from different angles. At last, they came to a conclusion
that there is no proper integration and connectivity between the application and the database system, that is, the application could not connect properly with the backend database system. Even IBM people could not solve the problem. Then, immediately, Oracle experts were requested to solve the problem. When they replaced the DB2 server database with their Oracle database software, the software application worked perfectly. From this experience, APTS stopped procuring DB2 database software and turned completely to Oracle software and that procurement continued for all future applications. This case will provide a clear evidence for the importance of adaptability of product in speeding up the procurement activity by making it successful.

(ii) When the value of the variable ‘Clarity of proposal’ is increased from 1 to 1.5, some improvement in the growth behaviour of the variable ‘Procurement rate’ and whereas a meager improvement in the growth behaviour of ‘Successful Procurement’ are observed, as shown in the figure, Fig. 5.3.1.6(ii). This observation says that increase in the clarity of proposal will speed up the procurement process by convincing the customer about the details of the product and other terms and conditions, but it shows slight influence over successful procurement, because a procurement is said to be successful when the features of the product and the services as detailed in the proposal work well.

*Fig.5.3.1.6(ii). Sensitivity analysis of ‘Successful Procurement’*
(iii) When the value of the variable, 'Skills of evaluators' is increased from 1 to 1.2, great improvement is observed in the system with 'Procurement rate' touching a final value near 130 and 'Successful Procurement' reaching a final value above 35. Usually, the skills of the evaluators to check the features and working of the product(s) or services are very important to improve the procurement process and make the procurement successful. Unless the evaluators evaluate properly and certify the features and usefulness of the product(s), the organization could not proceed further to procure the product(s).

In APTS, if latest hardware products are to be procured for the use of government departments, suppliers of those products will be requested to give demonstration (demo) and keep their items for a short time for the evaluation of APTS. During that time, some technical experts of APTS will run and test the items and submit a detailed report on the performance and usage of the product(s) along with their comments and recommendations. If the report on any product is positive, the purchases department considers procuring it. This case could validate the above sensitivity analysis result.

Fig. 5.3.1.6(iii). Sensitivity analysis of 'Successful Procurement'
(iv) When the value of 'Reputation of vendor' is increased from 1 to 1.5, some considerable improvement has been observed in the growth of 'Procurement rate' touching a final value just above 100, followed by a slight improvement in the growth of 'Successful Procurement' reaching a final value of 30. This result is validating the fact that the reputation of vendor plays an important role only in the initial stage of procurement process, but it will not highly influence the success of procurement.

![Fig. 5.3.1.6(iv). Sensitivity analysis of 'Successful Procurement']

(v) When the value of 'Financial settlements' is increased from 1 to 1.2, considerable improvement has been observed in the growth of performance of the procurement system. 'Procurement rate' reached a final value of 100, whereas 'Successful Procurement' touched a final value near 35. The increase in financial settlements is showing more influence on 'Successful Procurement' than on 'Procurement rate'. This result is validating the usual experience in procurement that the complete settlement of financial dues will be done only by the end of procurement and when such settlements have been well done, the procurement is said to be done with more success. Meanwhile step by step settlement of financial dues will definitely speed up the procurement process. Hence the sensitivity analysis result is well validated.
(vi) When the value of the variable ‘Timely delivery’ is increased from 1 to 1.2, considerable improvement is observed in the growth behaviour of ‘Successful Procurement‘ (touching a final value near 35) when compared with the growth in ‘Procurement rate’ (touching a final value of 100). This observation can be attributed to the fact that like financial settlements, timely delivery of the product(s) will speed up further procurement process and decide the success of the procurement.

APTS used to impose penalty on the delay made by the vendors in delivering the products as per agreement. While making final settlements of bills, the penalty amount would be deducted and balance amount paid to the vendor. It was observed that the implementation of such penalty system made the vendors deliver the product(s) or service(s) in time.
5.3.2. EFFECTIVE TENDER EVALUATION

The tender process generally consists of many stages like (1) Invitation to tender, (2) Preliminary phase of evaluation (evaluation of mandatory requirements), (3) Evaluation of business strengths of bidders, (4) Evaluation of technical strengths of bidders, (5) Evaluation of financial quotations submitted by bidders and (6) Finalization of successful bidder.

The 'invitation to tender' documents the customer requirements, needs, terms and conditions and also the eligibility of the bidder in different aspects like resources, business and technical capabilities. In response to the invitation to tender openly, generally many suppliers will submit their tender bids.

A tender bid normally consists of mandatory and desired requirements of the supplier/developer. If the tender bid does not meet the mandatory requirements, that proposal will be immediately rejected. Examples for mandatory requirements include payment of earnest money deposit (EMD) for participation in tender, nature of business of the bidder, etc. The evaluation process in this preliminary phase of tender process is to
check whether the bidder has paid the EMD amount, whether the bidder is in the same business line to handle the proposed work, etc.

The bids, that pass the preliminary evaluation phase, are eligible for the next stages of evaluation, namely, Business strengths, Technical, Financial quotation and Final evaluations. The number of phases of evaluation process can be modified depending on the customer's criteria, choices, resources and requirements.

In the business strengths evaluation phase, evaluation is focused on the business turnover of the bidder, for example, the business turnover in the last three financial years, that is, whether the business is running in profit or loss. Evaluation of other business strengths like availability of resources (both manpower and infrastructure), etc. may also be carried out. For this purpose, the bidders or their representatives may be interviewed and their development sites may even be visited.

In this context, one real world case observed during surveys is hereby mentioned. In one organization, it was found that a vendor bagged a project work on sub-contract basis by using the temporary services of experts working in well reputed organizations to act as their own technical staff during the interviews and initial interactions with the evaluators. This made the evaluators have the impression that the vendor had good technical staff. After signing the contract, when it was found that there was no progress in the work and there was no communication on the developments taking place, the vendor organization was visited by the staff of the user organization. To their surprise, they found no infrastructure, nor technical people, except two old personal computers and two trainee programmers. When the Chief of the organization was questioned, the questionable techniques used by the vendor to bag the project work were revealed and the user was very much frustrated. This case study supports and stresses the need and importance of physical visits to the vendor offices, questioning the vendor representatives about their qualifications, skills, experience, CVs, etc. and making sure that the details presented by the vendor in the bid or proposal are correct.
The technical (demonstration) phase may include the evaluation criteria items such as supplier’s level of analysis of the customer requirements, development skills, and presentation skills. For this evaluation phase, the bidders who were successful in the previous phase will be invited to demonstrate their solutions to the problems and requirements of the user in the form of displaying their products or prototypes.

Evaluation of financial quotations depends mainly on the price quoted by the bidder in the financial bid, which may be submitted in a separate sealed cover along with the tender bid. This phase may also include other criteria, namely, the bidder’s flexibility for negotiations on price and service. For this evaluation phase, the bidders qualified in the technical phase will be considered and their financial bids submitted will be opened in their presence.

The last phase, called the ‘Finalization of successful bidder’, evaluates the performance of the bidders in the technical phase in comparison with their financial quotes and subsequent negotiations held on price and services, and selects the successful bidder to award the work or purchase order.

When all the above phases of evaluation along with any further extra evaluation criteria are managed properly, the task of evaluation of tender bids will become complete and successful.

For procurement of IT products or services or automated equipment, APTS continuously issued tender notifications on behalf of different user Government departments and took up the job of evaluation of those tenders by recommending the successful vendor to the user department. Based on the type of product(s) or service(s), APTS evolved standard evaluation criteria to select the best vendors. As per the feasibility study conducted and recommendations made by APTS, a government department might request APTS for development of software applications or computerization of their office or procurement of large-scale equipment utilizing the sanctioned government funds. In the case of software application development or computerization of government office, APTS assesses the complexity of the work, checks whether APTS could handle it independently using its own
staff or to subcontract the work to other potential developers. For procurement of equipment or tools, APTS makes arrangements to contact the potential suppliers that were registered with APTS, negotiate and finalise the procurement. APTS also assisted some government departments to prepare and notify the requirement or tender document, evaluate the tender bids to select the potential supplier(s), award the work order and manage the contract till its successful completion.

In this process, M/s Indo Infotech, a software company located at Somajiguda, Hyderabad, bagged the project work order of budget data on disk, M/s ComVision (Secunderabad) bagged the projects of computerization of Directorate of School Education, Social Welfare department. Collegiate Education, etc., M/s Sagarsoft (Hyderabad) the computerization of A.P. Dairy Development Cooperative Federation, M/s RamInfo (Panjagutta, Hyderabad) bagged the projects of computerization of Commercial Taxes department and a part of Multi-Purpose House-hold Survey (MPHS), etc. All these developers, external to APTS, were selected by APTS as sub-contractors to do those projects. They bagged the work orders by competing in the tender process.

From the above discussions, the different salient variables that influence the system of effective tender evaluation have been identified and listed in Table 5.3.2.

| Table 5.3.2. List of salient variables in the system of ‘Effective Tender evaluation’ |
|---------------------------------|---------------------------------|
| 1. Fulfillment of tender requirements | 9. Technical skills of vendor |
| 2. Mandatory requirements | 10. Reliability in financial quote |
| 3. Desired requirements | 11. Flexibility for negotiations |
| 4. Demonstration skills of vendor | 12. Skills of evaluators |
| 5. Business strengths of vendor | 13. Invalid bids |
| 7. Infrastructure | 15. Incomplete bids |
| 8. Technical people | |


5.3.2.1. Basic SD feedback loops in the system of 'Effective Tender evaluation'

(a) The more the skills of the evaluators, the more will the effectiveness in the evaluation of tender bids and the more will be the successful tender bidding rate. Effective tender evaluation increases the successfulness of the bidding rate. Hence the causal links connecting the variable 'Skills of evaluators' with the two variables 'Successful bidding rate' and 'Effective tender evaluation' and also the causal link between the variables 'Successful bidding rate' and 'Effective tender evaluation' have been treated as positive links. The feedback loop formed by these three positive causal links will become a positive loop.

(b) If the vendor has more business strengths and more technical skills, the bid of that vendor will be given more preference and this condition leads to improved success in the bidding rate. Hence the causal links connecting the two variables, 'Business strengths of vendor' and 'Technical skills of vendor' to the variable 'Successful bidding rate' have been assigned positive signs. The increase in the number of technical people improves the business strengths and technical skills of the vendor organization and hence the causal links connecting the variable 'Technical people' with the two variables 'Business strengths of vendor' and 'Technical skills of vendor' have been treated as positive links. The feedback loop formed by these four positive causal links will also be positive.

The two feedback loops are shown in the figure, Fig. 5.3.2.1.

**Fig. 5.3.2.1. SD feedback loops in the system of 'Effective Tender Evaluation'**

![Feedback Loop Diagram](image)
5.3.2.2. Causal loop model of the system of ‘Effective Tender evaluation’

The tender bid requirements are classified into mandatory and desired requirements and when these requirements are fulfilled, the tender bid requirements are said to be satisfied and such bids will only be considered. Hence the causal links from the two variables, ‘Mandatory requirements’ and ‘Desired requirements’ connecting to the variable ‘Fulfillment of Tender requirements’ have been treated as positive links. Fulfillment of tender bid requirements leads to more successful tender bidding rate and hence the causal link between the variables, ‘Fulfillment of tender requirements’ and ‘Successful bidding rate’ has been assigned positive sign.

During evaluation of tender bids, if the tender is related to buying a product, the vendor should demonstrate well the features of the related product so as to impress the evaluators to gain more marks. Hence the causal link between the two variables, ‘Demonstration skills of vendor’ and ‘Successful bidding rate’ has been assigned positive sign. When the cost of the product(s) or service(s) quoted in the financial bid is so high, such tenders can not be successful in the tender bid race. Hence the causal link connecting the variable ‘Reliability in financial quote’ with ‘Successful bidding rate’ will be a positive causal link. When the bidder shows more tendency and flexibility for any negotiations required for the tender bid process, there will be more chances for consideration of such bids and there will be more success rate for such bids. Based on this point, the causal link between the variables, ‘Flexibility for negotiations’ and ‘Successful bidding rate’ has been treated as a positive link.

Good business turnover and possessing good infrastructure will generate good marks during evaluation of the business strengths of a vendor and hence the causal links from the two variables, ‘Business turnover’ and ‘Infrastructure’ connecting to the variable ‘Business strengths of vendor’ have been treated as positive links.

Any deviation from mandatory requirements will invalidate the tender bid. In addition, bid documents incomplete in furnishing required important information will also become invalid. Therefore, the causal links from the two variables ‘Deviation from mandatory
requirements’ and ‘Incomplete bids’ connecting to the variable ‘Invalid bid’ have been treated as positive links.

With the help of these causal links and the two feedback loops explained earlier, the causal loop model of the system of effective tender evaluation has been developed and is given in the figure, Fig. 5.3.2.2.

Fig. 5.3.2.2. Causal loop model of ‘Effective Tender Evaluation’
5.3.2.3. **Stock and Flow model of the system of ‘Effective Tender evaluation’**

To simulate the system of effective tender evaluation, the variables ‘Successful bidding rate’ and ‘Invalid bids’ have been treated as rate variables and whereas the variable ‘Effective tender evaluation’ has been treated as ‘flow’ (or ‘stock’) variable and the remaining variables as auxiliary variables. With these changes, a stock and flow model of the system of effective tender evaluation has been developed, as shown in the figure, Fig. 5.3.2.3.

**Fig. 5.3.2.3. Stock and Flow model of ‘Effective Tender evaluation’**

5.3.2.4. **Modeling equations for the system of ‘Effective Tender evaluation’**

For the system of effective tender evaluation, the simulation run time has been chosen as 2 months with a time step of 0.125 month. The initial value of the variable ‘Mandatory requirements’ has been assumed as 1 and for the variable ‘Desired requirements’ it has been
assumed as 0.75, because of the more weightage the mandatory requirements have. Since both the mandatory and desired requirements are vital tender requirements, the variable ‘Fulfillment of tender requirements’ has been equated to the sum of desired requirements and exponential of mandatory requirements. Each of the two variables ‘Business turnover’ and ‘Infrastructure’ has been assigned an initial value of 0.5, whereas the variable ‘Technical people’ has been assigned a value of 1. ‘Technical skills of the vendor’ has been equated to the value of the variable ‘Technical people’. That means the organization is supposed to have sufficient technical manpower having sufficient technical skills and moderate business turnover and infrastructure.

The variables, ‘Reliability in financial quote’, ‘Flexibility for negotiations’ and ‘Demonstration skills of vendor’ have been assigned the initial values of 0.75, 0.5 and 1 respectively. ‘Deviation from mandatory requirements’ has been initiated with nil value. Initial value of each of the two variables ‘Incomplete bids’ and ‘Skills of evaluators’ has been assumed as 1.

The variable ‘Business strengths of vendor’ has been expressed as the sum of ‘Infrastructure’ and double the values of the two variables ‘Business turnover’ and ‘Technical people’, so as to give more importance to the business turnover and possessing technical people. The variable ‘Invalid bids’ has been equated to the expression of sum of ‘Deviation from mandatory requirements’ and ‘Incomplete bids’.

The expression assigned to the variable ‘Successful bidding rate’ is somewhat lengthy formed by the combination of different variables, namely, ‘Business strengths of vendor’, ‘Reliability in financial quote’, ‘Technical skills of vendor’, ‘Demonstration skills of vendor’, ‘Flexibility for negotiations’, ‘Fulfillment of tender requirements’, ‘Skills of evaluators’ and ‘Effective tender evaluation’, as shown by the equation (16) in Table 5.3.2.4. Finally, the variable ‘Effective tender evaluation’ has been treated as the integration of the product of ‘Successful bidding rate’ and ‘Skills of evaluators’ with an initial value of 0 (nil).

All the modeling equations of ‘Effective Tender evaluation’ are listed in Table 5.3.2.4.
Table 5.3.2.4. *SD* modeling equations of the system of ‘Effective Tender evaluation’

(i) INITIAL TIME = 0  (The initial time for the simulation).
(ii) FINAL TIME = 2  (The final time for the simulation).
(iii) TIME STEP = 0.125  (The time step for the simulation).
(iv) SAVEPER = TIME STEP  (The frequency with which output is stored).

(1) Mandatory requirements = 1.
(2) Desired requirements = 0.75.
(3) Fulfillment of tender requirements = EXP(Mandatory requirements) + Desired requirements.
(4) Business turnover = 0.5.
(5) Infrastructure = 0.5.
(6) Technical people = 1.
(7) Technical skills of vendor = Technical people.
(8) Reliability in financial quote = 0.75.
(9) Flexibility for negotiations = 0.5.
(10) Demonstration skills of vendor = 1.
(11) Deviation from mandatory requirements = 0.
(12) Incomplete bids = 1.
(13) Skills of evaluators = 1.
(15) Invalid bids = Deviation from mandatory requirements + Incomplete bids.

Contd......
(16) \[ \text{Successful bidding rate} = (\text{Business strengths of vendor} + \exp(\text{Reliability in financial quote}) + \exp(\text{Technical skills of vendor}) + \text{Demonstration skills of vendor} + \text{Flexibility for negotiations} + (\text{Fulfillment of tender requirements}) \times \text{Skills of evaluators} + \text{Effective tender evaluation}. \]

(17) \[ \text{Effective tender evaluation} = \text{INTEG} (\text{Successful bidding rate} \times \text{Skills of evaluators}, 0). \]

5.3.2.5. Simulation results of the system of 'Effective Tender evaluation'

With the modeling equations assigned to the respective variables, the stock and flow model of the system of effective tender evaluation has been simulated. From the simulation run, exponential growth behaviour is observed in the two variables 'Effective tender evaluation' and 'Successful bidding rate'. The variable 'Effective tender evaluation', starting from an initial value of 0, grew to a value above 70; whereas the variable 'Successful bidding rate' started from a value of about 15 and ended at a value above 85. These results are graphically shown in the figure, Fig. 5.3.2.5.

**Fig. 5.3.2.5. Patterns of growth behaviour in the system of 'Effective Tender evaluation'**

![Graph showing patterns of growth behaviour in the system of 'Effective Tender evaluation'](image)
5.3.2.6. Sensitivity analysis results of the system of 'Effective Tender evaluation'

The result of every sensitivity analysis is represented by graph II (blue colour), whereas the respective initial simulation result is shown by graph I (red colour) for comparison.

(i) When the value of the variable, 'Technical people' is increased from 1 to 1.5, there is considerable improvement in the growth behaviour of both variables, 'Effective tender evaluation' (touching a final value near 85) and 'Successful bidding rate' (touching a final value just above 100). This observation can be attributed to the fact that in any tender process pertaining to purchase of technical goods or services, the vendor having good number of technical people will be given more preference and such bids will be given more importance. Hence the sensitivity analysis result has been well validated.

Fig. 5.3.2.6(i). Sensitivity analysis of 'Effective Tender evaluation'

Other variables, namely, 'Infrastructure', 'Business turnover', 'Demonstration skills of vendor', 'Desired requirements' and 'Flexibility for negotiations' have shown very less influence even though the value of any one of them is doubled. When mandatory requirements are fulfilled, only then the tender evaluation process of that tender bid starts.
Hence the sensitivity analysis by changing the value of mandatory requirements is out of question.

(ii) When 'Skills of evaluators' is increased from 1 to 1.125, that slight increase produced a great improvement in the performance of the system. 'Effective tender evaluation' crossed a final value of 100 when compared with the final value reached in the initial simulation run (near 70) and 'Successful bidding rate' reached a final value just below 125 (this value in the initial run is near 85).

In APTS, for different phases of evaluation of tenders, different groups of experts will be selected. For evaluation in technical (demonstration) phase, sometimes, even external experts will be invited, if necessary, to make the evaluation process more effective and successful.

![Graph of Effective Tender Evaluation and Successful Bidding Rate](image)

(iii) When 'Reliability in financial quote' is increased from 0.75 to 1, some considerable improvement is observed in the performance of the system. The variable, 'Effective tender evaluation' touched a final value near 90 and 'Successful bidding rate' reached a
final value of 100. But these improvements are not comparable with those results as obtained from the increase in the value of any of the two variables, ‘Technical people’ and ‘Skills of evaluators’.

In APTS, in one tender, the vendor that scored the highest marks in technical (demonstration) phase failed to bag the project in the final phase, because the financial quote submitted by that vendor was very high and unreliable, when compared with those of other competing vendors. Even the plea of the vendor to bring down the quote to the minimum level was not entertained by majority of the evaluators. This case says that unreliable quotes may lead to many problems like loss of trust, opportunities, etc. This real-world example validates the sensitivity analysis result.

Fig. 5.3.2.6(iii). Sensitivity analysis of ‘Effective Tender evaluation’
5.3.3. BIT DECISION MAKING (BDM) METHOD

A lot of decision making methods are available in different fields. Decision making environments enable formulating helpful mathematical models (linear programming, nonlinear programming, etc.) with objective functions that specify the estimated consequences of any combinations of decisions (Hiller and Lieberman 2001).

There are some systems where a firm decision, i.e., either 'yes' or 'no' is to be taken for each criteria issue present therein and there will not be any scope for weighing the decision in between those two cases (that is, some 'yes' and some 'no'). The number of such criteria issues varies differently in different systems, and in big and complex systems the number may be very large. In some cases, when a complex system is divided into a reasonable number of sub-systems, the decision process in each such sub-system consisting of a limited number of criteria issues can be treated as a separate phase in the total decision process.

In the present research work, a new decision making system, named as Bit Decision Making (BDM) method has been proposed using simple Boolean algebra. The BDM method, by the way of applying Boolean logic and simple Boolean algebra, automates the decision process in each phase and thereby the whole system as well to make a final decision. The preliminary work on this method was already reported by the author in an International Conference held in Singapore (Jigeesh 2003). The present work elaborates the method to further strengthen its scope of application to management of projects. To have clear understanding about the method and its applications, an example of application of BDM method to the system of evaluation of IT tenders has been detailed covering different stages of tender evaluation - 'Invitation to tender', 'Business strengths', 'Technical', 'Financial quotation' and 'Final evaluation'. The process of evaluation of tenders has already been described in the section 5.3.2 dealing with the system of 'Effective Tender evaluation'.

The 'invitation to tender' documents the customer requirements, needs, terms and conditions and also the eligibility of the bidder in different aspects like resources, business and technical capabilities. Responding to the invitation to open tendering, generally, many suppliers submit their tender bids along with earnest money deposit (EMD), which is the primary
requirement for participating in the open tendering. The evaluation process in this preliminary phase is to check simply whether the bidder has paid the EMD amount and also whether the bidder is in the same business line to handle the proposed task. These two criteria items will become the mandatory requirements of tender bidding. The list of requirements may be enhanced based on the user's plan and vision by including some more criteria items.

The bids, that pass in the preliminary evaluation phase by meeting the mandatory requirements, are eligible for the next stages of evaluation, namely, Business strengths, Technical, Financial quotation and Final evaluations. The number of phases of evaluation process can be modified depending on the customer's criteria, choices, resources and requirements.

In the business strengths evaluation phase, evaluation is focused on the business turnover of the bidder, say, business turnover during the last three financial years examining whether the business is running on profit or loss, and also the availability of resources (both manpower and infrastructure). The technical (demonstration) phase includes the evaluation criteria items such as supplier's analysis of the customer requirements, development skills, and presentation skills. Financial quotation evaluation phase depends mainly on the price quoted by the bidder in the financial bid, which will be submitted in a separate sealed cover along with the tender bid. This phase may also include another criteria item, the bidder's flexibility for negotiations on price and service. The last phase, called the final phase of evaluation, finalizes the successful bidder to award the work or purchase order.

5.3.3.1. Introduction to Binary digits, Boolean logic and algebra

Binary number system is used in computers. In this number system, the base is '2' just like 10 as base for the common decimal number system. In the decimal number system, the different combinations of the ten digits from 0 to 9 are used to represent a decimal number. In the same way, in binary number system, its two digits '0' and '1' are used to form a binary number. Each of these two digits is called a binary digit or simply 'bit'. In computers, these two bits are used to represent 'OFF' or 'ON' conditions, 'YES' or 'NO'
decisions, 'TRUE' or 'FALSE' selections. If 'OFF' condition is represented by '0', 'ON'
condition is represented by '1' and similar is the case with other options. This is called
Boolean logic.

Like decimal system, binary system has its own algebra based on the Boolean logic. The
proposed BDM method uses only addition and multiplication operations and hence those two
operations only are described below for ready reference to the foregoing issues covered in
this chapter. In binary methodology, the table consisting of the combinations of input bits
and their resulting outputs is referred to as a 'truth table'.

Addition: In Boolean algebra, the 'OR' or '+' operation denotes the addition operation. If
'A' and 'B' are two binary digits and 'Y' represents result of adding these two digits, the
following truth table results.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>Y = A + B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

When two '1's are added, the result is 10 in the binary number system. Here, '1' is called
the carrier. If we want to restrict the result to only one digit, the carrier will be suppressed
and the result will become '0'. In the present method, as decisions are represented by the
binary digits (bits), the single digit representation of decision has been implemented by
suppressing the carrier to limit the output to a single digit.

Multiplication: The multiplication operation is referred to as 'AND' (\( \cdot \)) operation in
Boolean algebra. The truth table for multiplication (AND) operation is shown below:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>Y = A \cdot B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
5.3.3.2. Bit Decision Making (BDM) method

In this method, each of the inputs and the outputs in any process is assigned a binary digit (bit) value, i.e., either 1 or 0. For an output derived from two or more input values also, its value is limited only to a single bit, which is the last bit, by suppressing the carrier, if any. Hence the whole system will be designed to have bit values, either ‘1’ or ‘0’. For example, if an output is a result of addition of two input bit values, the addition 1+0 results ‘1’, but 1+1 results only ‘0’ (the carrier ‘1’ is suppressed) to limit the output value to single bit. Thus, the Boolean logic, ‘yes or no’ or ‘true or false’, is embedded in the BDM method for both input and output values.

It is the user that decides to assign either ‘1’ or ‘0’ to the selected input criteria item based on the analogy and logic the organization adopts, weighs and treats correct. Thus, after assigning binary digits to different criteria items in a sub-system, the user has to again decide the result of their output, i.e., either to assign ‘1’ or ‘0’ based on the decision strategy to be implemented by the organization. This method of assigning binary values to inputs and outputs generates different patterns of their combination in different phases of evaluation and each combination of inputs has an output. The analogy and logic followed for a particular phase should be treated as standard for that evaluation phase and a standard mathematical equation should be generated using Boolean algebra by correlating the inputs to their respective output. Any change in the analogy and logic results changes in the binary values of the inputs and their output, thereby leading to changes in the correlation equation.

BDM method can be applied to any simple or complex decision systems. In the case of complex systems, the system can be further divided into a reasonable number of independent and manageable sub-systems and each such sub-system is treated with the above procedure and a unique mathematical correlation equation will be developed for it. This needs thorough study and analysis of each sub-system which is to be fed with input and output values based on the appropriate criteria items required for decision making and also the analogy and logic to be implemented therein to take decision.
5.3.3.3. Application of BDM method to the process of evaluation of IT tenders

The application of BDM method to all the phases of IT tender evaluation process is detailed below starting from preliminary phase.

5.3.3.3(i). Preliminary Phase

The evaluation process in this phase is to check whether the bidder has satisfied the mandatory requirements of the tender, like paying the EMD amount and continuing in the same line of business. If these two issues are considered as two criteria items, they can be represented as EMD payment \((X_1)\) and same business line \((X_2)\). Following BDM method, if ‘1’ is assigned to \(X_1\) to represent a positive response, i.e., EMD is paid, ‘0’ will be assigned to the negative response, i.e., EMD is not paid. In the same way, ‘1’ is to be assigned to \(X_2\), if the bidder is in the same line of business or else ‘0’ is to be assigned. Assignment of bit values in this way generates a maximum of four possible patterns \((A, B, C, D)\) of combination of input and output values. A truth table, Table 1, can be developed using these inputs and their result.

<table>
<thead>
<tr>
<th>Criteria Item</th>
<th>Possible patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X_1) (EMD payment)</td>
<td>A     B     C     D</td>
</tr>
<tr>
<td></td>
<td>1     1     0     0</td>
</tr>
<tr>
<td>(X_2) (same business line)</td>
<td>1   0   1   0</td>
</tr>
<tr>
<td>Output</td>
<td>1     0     0     0</td>
</tr>
</tbody>
</table>

The assignment of digits in the above table and the output drawn up will be through application of simple logic by the user. For example, in pattern C, when EMD is not paid means the bidder is not at all eligible to participate in the tender even though the bidder is in the same business line. Hence the output is ‘0’. Similarly, payment of the EMD alone does not qualify the bidder unless the bidder is in the same business line. This case is represented by pattern B.

From the above possible patterns, the expression for the output \(Y_1\), can be generated using Boolean algebra as,

\[ Y_1 = X_1 \cdot X_2. \]  \(\text{(A)}\)
In the above equation, simple 'AND' (.) operation has been used between the two variables, $X_1$ and $X_2$.

5.3.3.3(ii). Business Strengths Phase

In this case, the input criteria items considered are the turnover for the last three financial years, strength of technical staff, and infrastructure availability. For the last three years, the business turnover of each year is to be checked, i.e., whether profit or loss. If it is profit, assign '1' and if loss, assign '0'. So there are three input criteria elements for the turnover of the last three years — $X_3$, $X_4$, and $X_5$. Here, a constraint of having profit at least once during the last three financial years may be laid down to consider bidders. That means, a bidder having no profit at least once during the last three years can be eliminated. For the criteria issue of strength of technical staff ($X_6$), if it is satisfactory, assign '1' or else assign '0'. In the case of infrastructure availability ($X_7$) also, the binary values are assigned similarly. Thus, Table II is the resultant truth table for this phase.

The patterns include the bidders having profit in every year, twice and only once during the last three years respectively along with their strengths in manpower and infrastructure. The important constraint used for evaluation regarding turnover is added at the bottom of table.

**Table II. Truth table for the Business strengths phase**

<table>
<thead>
<tr>
<th>Criteria item</th>
<th>Possible patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_3$ (1st year business)</td>
<td>A</td>
</tr>
<tr>
<td>$X_4$ (2nd year business)</td>
<td>1</td>
</tr>
<tr>
<td>$X_5$ (3rd year business)</td>
<td>1</td>
</tr>
<tr>
<td>$X_6$ (Technical staff)</td>
<td>1</td>
</tr>
<tr>
<td>$X_7$ (Infrastructure)</td>
<td>1</td>
</tr>
<tr>
<td>Output</td>
<td>1</td>
</tr>
</tbody>
</table>

*(Constraint: There should be profit at least once during the last three financial years)*
The way the output is derived is through applying some relevant logic and strategy, which may be quite difficult in some cases like patterns J and K. There, even though the bidder is having profit at least once during the last three years, the bidder has failed in having either satisfactory strength of technical people or infrastructure, which may not be acquired immediately due to financial losses for the last two years, in case the bidder is awarded the work. In the case of patterns F and G wherein the bidder is in profit for two years, it is assumed that the bidder is financially capable to strengthen either infrastructure facilities or technical staff. Regarding the pattern I, even though the bidder has profit only once in the last three years, the bidder is having good strength of technical staff and infrastructure and hence it is assumed that the bidder can survive and do the things well, in case the work order is awarded. Based on this strategy, the output is assigned a value ‘1’ in order to consider those bidders. The ultimate correlation equation derived from the truth table is

\[
Y_2 = (X_3, X_4 + X_4, X_5 + X_3, X_8). (X_5 + X_7) + X_6, X_7. \tag{B}
\]

5.3.3.3(iii) Technical (Demonstration) Phase

The bidders qualified in the above two phases may be asked to demonstrate their product(s) if the purpose of tender is to purchase product(s), or to develop a prototype application according to the requirements of the user if the purpose of the tender is to develop an application or service. Here, three criteria items may be identified by taking into view the importance of bidder’s analysis of user’s requirements (X8) and skills in development (X9) and presentation (X10). It has been assumed to consider a bidder who passes in at least two out of the three evaluation criteria issues (X8, X9, X10). The resultant truth table is Table III.

**Table III. Truth table for the Technical phase**

<table>
<thead>
<tr>
<th>Criteria item</th>
<th>Possible patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>X8 (Analysis)</td>
<td>1</td>
</tr>
<tr>
<td>X9 (Development)</td>
<td>0</td>
</tr>
<tr>
<td>X10 (Presentation)</td>
<td>1</td>
</tr>
<tr>
<td>Output</td>
<td>1</td>
</tr>
</tbody>
</table>
The equation correlating the output to the inputs is as follows.

\[ Y_3 = X_8 \cdot (X_9 + X_{10}) + X_9 \cdot X_{10}. \]  

\[ \text{(C)} \]

5.3.3.3(iv). Financial Quotation Phase

The bidders who get through successfully from the third phase of evaluation will be invited to attend the event of opening of their financial bids. After opening the financial bids, the rates quoted by different bidders are listed to start the evaluation exercise. This phase of evaluation includes checking the price quoted by the bidder for the product or service and the bidder’s flexibility for negotiations on price or services. From the list of prices, if the price quoted by a bidder is considerably high, ‘0’ is to be assigned to the criteria item, \( X_{11} \), i.e., quoted price, and for considerable low and reasonable price quotes ‘1’ is to be assigned. If the bidder is ready for negotiations, 1 is to be assigned to the variable, \( X_{12} \), and 0 otherwise. Even though a bidder quotes high price, the bidder can be considered on the grounds of flexibility for negotiations. Table IV is the resultant truth table.

<table>
<thead>
<tr>
<th>Criteria item</th>
<th>Possible patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_{11} ) (quoted price)</td>
<td>A     B     C     D</td>
</tr>
<tr>
<td>( X_{12} ) (flexibility for negotiations)</td>
<td>1     0     1     0</td>
</tr>
<tr>
<td>Output</td>
<td>1     1     1     0</td>
</tr>
</tbody>
</table>

Following the possible patterns as shown in the table, the resultant correlation equation is

\[ Y_4 = X_{11} + X_{11} \cdot X_{12}. \]  

\[ \text{(D)} \]

5.3.3.3(v). Final Phase of Evaluation

Of all the phases of evaluation, this is a critical phase because of finalising the successful one from the competing bidders. For this purpose, the user may evolve their own genuine
strategy or use any other general strategy. The customer may also combine the results of both third (technical) and fourth (financial) phases of evaluation to take a decision. For example, the customer may pick up the bidders who have scored '1' for all the criteria items under the technical phase and check whether they have passed in the financial phase. For such bidders, '1' is to be assigned for the criteria item T (Technical Phase), and '0' otherwise; that mean the bidder did not score 1 for all the criteria issues in the technical phase, but passed. Similar is the case in 'Business strengths phase'. If more bidders are found passed in this way, the bidders who have scored '1' for the two criteria items in the financial phase can be considered. Then also, if a number of competing bidders are resulted, a bidder can be finally selected based on the negotiations held on price and services.

**Integrated Evaluation Process**

This is an integrated approach where the bidders qualified in the preliminary phase and their resultant scores in the following phases are grouped together to prepare a consolidated statement to view the results at one place and make ultimate decisions. This integrated evaluation process will be helpful to the final phase of evaluation for finalizing the successful bidder. Here, different patterns of values can be represented with different combinations of the results of different phases of evaluation and for each pattern appropriate output value can be derived using proper strategy. A truth table, Table V has been developed for this integrated process.

<table>
<thead>
<tr>
<th>Criteria Item</th>
<th>Possible patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (Preliminary phase)</td>
<td>1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>S (Business strengths phase)</td>
<td>1 1 1 1 0 0 0 0</td>
</tr>
<tr>
<td>T (Technical phase)</td>
<td>1 1 0 0 0 1 1 0</td>
</tr>
<tr>
<td>Q (Financial Quotation phase)</td>
<td>1 0 0 1 1 1 0 0</td>
</tr>
<tr>
<td>Output</td>
<td>1 1 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>
From the scenario of criteria items representing each phase and the possible patterns, the correlation equation between the input values and the ultimate output values can be expressed as,

\[ Y_s = T \cdot (S + Q) + Q \cdot (P + T) \]  

(E)

Looking at the values of inputs, one can have the idea of changing the equation (E) simply as, \( Y_s = P \cdot S \cdot T \). But the criteria item, \( Q \) (the result of Financial Quotation phase), which is very important, will miss without showing its valuable influence in evaluation. Hence, in order to include the contribution of all the criteria items considered in this integrated system, equation (E) has been formulated.

### 5.3.3.4. Features of BDM method

From the above discussions and explanation about the methodology and application of BDM method, the following features of the method have been summarized:

**(i) Granularity:** In BDM method, a complex system can be divided into a reasonable number of independent, meaningful and manageable sub-systems or phases to ease the decision making process. The size of the resulting grain of decision system can be decided by the senior management and the experts appointed by the user organization.

**(ii) Flexibility:** Based on the criteria items useful for decision making in each phase, possible patterns of combination of input values and the ultimate output value can be generated. The patterns with the same input values need not result the same output value in different phases. This is due to the difference in using specific logic and analogy in different phases. This is evident from the truth tables, Table I and Table IV, wherein the same input patterns are present but with different outputs. Hence the results of a decision system can be changed based on the logic used and accordingly a mathematical equation can be derived correlating the inputs to the ultimate output. However, the correlation equation will also be different
for different systems. This way, the BDM method provides a lot of flexibility to change criteria items, their values and the ultimate output values depending upon the strategy and logic the user wants to implement in a particular evaluation phase.

(iii) Standardization: Once the equations correlating the inputs to the output are derived for each phase, they will act as evaluation standards to automate the decision making process. This way of standardizing decision making in each phase leads to the formation of a standard decision making system for the whole complex process.

(iv) Integration: A consolidated processing system can be designed by treating each phase as one criteria item and its different results as the inputs to the total system and then deriving the ultimate output value for each pattern of such input values. Thus, in BDM method, all the sub-systems or phases can be brought together in the form of criteria items to form an integrated system.

The results provide wide scope for application of BDM method to any system for easing the process of decision making and control. The method can be applied to any field.
5.4. PROJECT MONITORING
Once the execution work starts, the project needs regular monitoring to find out what is happening and comparing it with current targets. This guides to exercising control over the project to take appropriate actions to achieve the planned targets. Monitoring is a direct connection between planning and control activities of the project and the best source of items to be monitored is the project’s action plan. Performance criteria, standards, and data collection procedures must be established for each of the factors to be measured and monitored.

Project monitoring includes monitoring current status of the project in terms of schedule and cost, monitoring cost and time to complete the project, monitoring potential problems that need to be addressed currently, monitoring causes for cost or schedule overruns, if any, and monitoring achievement from the money spent. Monitoring also includes the activities of forecasting cost overruns and identification of potential problems before it is too late to correct them. Earned value (EV) analysis is a technique used in project monitoring to analyse the percent of the original budget that has been earned by the actual work completed. It facilitates a good solution to do all these jobs of project monitoring. Hence the present research work has sub-divided the project monitoring phase into two major activities, simple monitoring and earned value analysis.

5.4.1. MONITORING
Monitoring mainly focuses on the action plan or project schedule, costs and resources. As per the priorities and duration of the activities as planned in the action plan, the sequence and progress of the activities need to be monitored. To do these tasks, every time the availability of resources and their performance will be assessed. Day to day expenses incurred on the project activities have to be monitored to check with the budget scheduled. The achievement of targets and the pending works should also be assessed to get clear picture of the status of the project from time to time. The potential problems that affect the project activities should be identified along with their causes and reported to take immediate rectification actions. When all these activities of project monitoring are carried out from time to time, the project progress can be easily assessed and forecasted.
In many organizations surveyed, it has been observed that the project manager makes daily routine rounds to the developers and watches the work going on, arranges frequent meetings with the project leaders and other developers to discuss about the status of activities, and lists the activities that are lagging behind the schedule and budget and inquire into the issues that cause problems and note all these observations. Whereas in a few organizations, it was observed that the project manager sticks on to chair doing some deskwork, issues always orders and calls the subordinate staff to the room and questions about the progress. In such environments, it was found that the quality of the projects was lacking in many aspects.

The findings and observations made during monitoring will serve as a base to solve the problems and improve the progress of the project. Periodic monitoring and measuring the status of the project allows for comparisons of actual versus expected plans. Frequent status reports allow for early detection of variations from plan and early corrections of causes. Usually status reports should be generated as frequently as possible to be useful and allowed for proactive correction.

It has been observed in almost all the IT departments surveyed in both India and Malaysia that regular meetings will be held by the Senior Management with the Project managers and Project leaders concerned to discuss about the status of ongoing projects. The meetings focus on issues like problems, constraints, requirements, progress, forecasting the cost and time to complete projects, etc. If deviations from plans are significant, corrective action will be required to bring the project back into track with the original or revised plan. In practice, the deviations from the plan may be causing delays in meeting the target dates and hence costs are going over the target.

It was also observed from the surveys that when the deviations from the original scheduled plan are anticipated/found, the reasons will be analysed in depth and all efforts will be applied by the project manager for smooth running of the project by supplying additional resources, if necessary, or by revising the plan by including necessary changes in time, cost, resources, etc. The second option will be the final alternative when the things are moving away from control.
Based on the above discussions, the important salient variables that influence the activity of project monitoring have been identified and listed in Table 5.4.1.

**Table 5.4.1. Salient variables that influence the system of 'Project Monitoring'**

<table>
<thead>
<tr>
<th>Salient variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Costs</td>
</tr>
<tr>
<td>2. Direct costs</td>
</tr>
<tr>
<td>3. Overhead costs</td>
</tr>
<tr>
<td>4. General and administrative costs</td>
</tr>
<tr>
<td>5. Action plan</td>
</tr>
<tr>
<td>6. Activities</td>
</tr>
<tr>
<td>7. Priority</td>
</tr>
<tr>
<td>8. Duration</td>
</tr>
<tr>
<td>9. Resources</td>
</tr>
<tr>
<td>10. Forecast of the project progress</td>
</tr>
<tr>
<td>11. Availability</td>
</tr>
<tr>
<td>12. Performance</td>
</tr>
<tr>
<td>13. Potential problems</td>
</tr>
<tr>
<td>14. Causes for problems</td>
</tr>
<tr>
<td>15. Project status</td>
</tr>
<tr>
<td>16. Achievement</td>
</tr>
<tr>
<td>17. Pending works</td>
</tr>
</tbody>
</table>

Using the above variables, an SD influence diagram has been developed, as shown in the figure, Fig. 5.4.1.

**Fig. 5.4.1. SD influence diagram for the system of 'Project Monitoring'**

- Direct costs
- Overhead costs
- General & Administrative costs
- Costs
- Activities
- Priority
- Durations
- Resources
- Availability
- Performance
- Project Monitoring
- Forecast of the project progress
- Potential problems
- Causes for problems
- Project status
- Achievement
- Pending works
5.4.2. EARNED VALUE ANALYSIS

Earned value is the percent of the original budgeted completion price that has been earned by the actual work completed. The acronym for this value is BCWP (Budgeted Cost of the Work Performed). Two key methods of earned value analysis are: (i) comparison of earned value with the expected schedule value, and (ii) comparison of earned value with the actual costs. These comparisons can be made at the project level or down to the cost account level. It is useful for determining project status for the latest period, all periods to date, and estimated to the end of the project. (Gray and Larson 2003).

The different terms useful for earned value analysis are defined (Chandra 2000, Gray and Larson 2003, and Cleland and Ireland 2002) below:

(1) BCWS (Budgeted cost of the work scheduled) is the cost estimate of the resources scheduled in a time-phased cumulative baseline budget.
(2) BCWP (Budgeted cost of the work performed) is the earned value or original budgeted cost for work actually completed.
(3) ACWP (Actual cost of the work performed) is the sum of the costs incurred in accomplishing the actual work.
(4) CV (Cost variance) represents an over- or under-expenditure from the planned project cost as of the date of measurement. It is calculated as $CV = BCWP - ACWP$. A positive value of $CV$ indicates expenditures less than planned and a negative value indicates greater cost than planned.
(5) CPI (Cost performance index) represents the efficiency of the work effort. It is calculated as $CPI = BCWP/ACWP$. If the value of CPI is greater than 1, it indicates greater efficiency than the planned and the value less than 1 indicates less efficiency than planned.
(6) SV (Schedule variance) represents an over- or under-time from the planned project schedule as of the date of measurement. It is calculated as $SV = BCWP - BCWS$. A positive value of $SV$ indicates the schedule is ahead of the plan; a negative value indicates the schedule is behind the plan.
(7) SPI (Schedule performance index) represents the effectiveness of the work effort. It is calculated as SPI = BCWP/BCWS. If SPI is greater than 1, it indicates better effectiveness than the planned and the value less than 1 indicates less effectiveness than planned.

(8) BAC (Budget at completion) is the total budgeted cost of the baseline or project cost accounts, which includes any increases or decreases in the money value resulting from changing the scope of the work.

(9) EAC (Estimate at completion) is the total estimated cost to complete the project and it includes all the costs to-date plus revised estimated costs for the work remaining.

(10) ETC (Estimate to complete) is the remaining cost for completing the project. It is calculated as ETC = (Work remaining)/CPI, or ETC = (BAC - BCWP)/CPI.

(11) FAC (Forecasted costs at completion) is the forecasted total cost at completion of the project. It is calculated as, FAC = ACWP + ETC.

(13) VAC (Variance at completion) indicates expected actual over- or under-run at completion. It is calculated as, VAC = BAC - EAC, or VAC = BAC - FAC.

Forecasting final project cost: Basically, there are two methods used to revise estimates of future project costs. The first method allows experts in the field to change original baseline durations and costs because new information tells them that the original estimates are not accurate. EAC can be used to represent revisions made by experts and practitioners associated with the project. The revisions from project experts are almost always used on smaller projects.

For large projects, a second method is used, where the original budget is less reliable to date. In this case, CPI is applied to the work remaining. When the forecast for completion uses the CPI as the basis for forecasting cost at completion, the acronym FAC (forecasted total cost at completion) is used.

From the surveys, it has been observed that the activity of earned value analysis is seldom used, though the organizations are well aware of its best features and uses. However, based on the importance and usefulness of the earned value analysis in project monitoring, it has been attempted to model and simulate it in the present work.
The important salient variables that compose and influence the system of earned value analysis have been identified and listed in Table 5.4.2.

<table>
<thead>
<tr>
<th>Salient variables</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cost adding rate</td>
<td>11. SPI</td>
</tr>
<tr>
<td>2. Estimated cost of work package</td>
<td>12. CV</td>
</tr>
<tr>
<td>3. Estimated effort for work package</td>
<td>13. CPI</td>
</tr>
<tr>
<td>4. Estimated cost of unit effort</td>
<td>14. BAC</td>
</tr>
<tr>
<td>5. Actual cost</td>
<td>15. EAC</td>
</tr>
<tr>
<td>6. Delay time</td>
<td>16. Work remaining</td>
</tr>
<tr>
<td>7. BCWS</td>
<td>17. ETC</td>
</tr>
<tr>
<td>8. BCWP</td>
<td>18. FAC</td>
</tr>
<tr>
<td>9. ACWP</td>
<td>19. VAC</td>
</tr>
<tr>
<td>10. SV</td>
<td></td>
</tr>
</tbody>
</table>

5.4.2.1. Basic SD feedback loops in the system of ‘Earned value analysis’

Depending on the influences identified among different salient variables in the system of ‘Earned value analysis’, twelve different feedback loops have been formed and are shown in the figures, Fig. 5.4.2.1(i) and Fig. 5.4.2.1(ii). The feedback loops are described below:

(a) The increase in budgeted cost of the work scheduled (BCWS) increases the addition of project cost and also the budgeted cost of the work performed (BCWP). Hence the causal links connecting the variable ‘BCWS’ to the two variables, ‘Cost adding rate’ and ‘BCWP’ are positive links. Increase in estimated effort for a work package increases its cost and BCWP as well. The causal links from ‘Estimated effort for work package’ to the two variables, ‘Estimated cost of work package’ and ‘BCWP’ have been treated as positive links. When the estimated cost of work package increases, the cost adding rate also increases and so the causal link between ‘Estimated cost of work package’ and ‘Cost adding rate’ is a positive link. The feedback loop formed by these five positive links will be a positive loop.
(b) The causal links from 'Estimated effort for work package' to 'Estimated cost of work package' is positive. Increase in estimated effort for work package also increases BCWP and hence the causal link between them is positive. When the estimated cost of unit effort is increased, the estimated cost and the actual cost of the work package also increase. Hence the causal links connecting 'Estimated cost of unit effort' to 'Estimated cost of work package' and 'Actual cost' are positive. When the work is delayed badly, the actual cost and BCWP increase and hence the causal links from 'Delay time' to 'Actual cost' and 'BCWP' are positive links. The feedback loop formed by these six positive links will also be positive.

(c) The causal links connecting 'Delay time' to 'BCWP' and 'Actual cost' are positive. When BCWP increases, the cost variance (CV) between BCWP and actual cost of the work performed (ACWP) increases. The causal link between BCWP and CV is a positive link. The increase in ACWP also increases the cost variance and the actual cost and hence the causal links connecting 'ACWP' to 'CV' and 'Actual cost' are positive. The feedback loop formed by these five positive links will be a positive loop.

(d) The causal links from 'Estimated cost of unit effort' and 'Actual cost' and that from 'ACWP' to 'Actual cost' are all positive links. Increase in estimated cost of unit effort and the ACWP result in the increase of the total estimated cost to complete the project (EAC) and hence the causal links from 'Estimated cost of unit effort' and 'ACWP' connecting to 'EAC' are positive. The feedback loop formed is a positive loop.

(e) The causal links from 'BCWP' and 'ACWP' to 'CV' are positive. Increase in BCWP means that more work has been performed and hence it improves the efficiency of the work effort and cost performance index (CPI = BCWP/ACWP). Whereas the increase in ACWP reduces CPI, because it increases the cost of the actual work performed, but not the quantity of work. Hence the causal link from 'BCWP' to 'CPI' is positive and that from 'ACWP' to 'CPI' is a negative link. The ultimate feedback loop formed by the three positive causal links and one negative link will be a negative loop.
(f) The causal link from ‘BCWS’ to ‘BCWP’ is positive. Increase in BCWS decreases the effectiveness of the work effort, that is, schedule performance index (SPI = BCWP/BCWS). But the increase in BCWP increases SPI, because of performing more work. Hence the causal link from ‘BCWS’ to ‘SPI’ is a negative link and that from ‘BCWP’ to ‘SPI’ is a positive link. The feedback loop formed by the two positive causal links and one negative link will be a negative loop.

(g) The causal link from ‘BCWS’ to ‘SPI’ is negative and that from ‘BCWP’ to ‘SPI’ is a positive link. Increase in either BCWS or BCWP increases the schedule variance (SV = BCWP - BCWS) and hence the causal links from ‘BCWS’ and ‘BCWP’ connecting to ‘SV’ are positive links. The ultimate feedback loop formed by the three positive links and a single negative link will be a negative loop.

(h) Increase in BCWS increases the ultimate total budget cost of the baseline, that is, budget at completion (BAC) and hence the causal link from ‘BCWS’ to ‘BAC’ is positive. The causal links from ‘BCWS’ and ‘BCWP’ to ‘SV’ are positive links. When the BCWP increases, that means more work has been performed, the pending work will be reduced. The causal link from ‘BCWP’ to ‘Work remaining’ is negative. When BAC increases, the work to be done will be more and hence the causal link from ‘BAC’ to ‘Work remaining’ is positive. The feedback loop formed by these four positive links and a single negative link will be a negative loop.

(i) The causal links from ‘BCWP’ connecting to ‘Work remaining’ and ‘CPI’ are negative and positive ones respectively. More pending work increases the remaining cost for completing the project, that is, the estimate to complete (ETC), which can be reduced with the increase in efficiency of work effort (CPI). Hence the causal links from ‘Work remaining’ and ‘CPI’ connecting to ‘ETC’ are positive and negative ones respectively. The feedback loop formed by the two positive and two negative links will be a positive loop.

(j) The causal link from ‘ACWP’ to ‘CPI’ and that from ‘CPI’ to ‘ETC’ are negative links. When ETC is increased, the forecasted costs at completion (FAC = ACWP + ETC) will be
increased. Increase in ACWP also increases FAC. Hence the causal links from ‘ACWP’ and ‘ETC’ connecting to ‘FAC’ are positive. The feedback loop formed by the two positive and two negative links will be a positive loop.

(k) When the pending work increases, ETC and EAC increase and hence the causal links from ‘Work remaining’ connecting to ‘ETC’ and ‘EAC’ are positive links. Also the causal links from ‘ETC’ and ‘ACWP’ connecting to ‘FAC’ are positive links. The causal link from ‘ACWP’ to ‘EAC’ is a positive link. The feedback loop formed by all these five positive links will be a positive loop.

(l) Increase in BAC also increases the variance at completion (VAC = BAC = EAC = BAC = FAC) and also the pending work. The causal links from ‘BAC’ connecting to ‘VAC’ and ‘Work remaining’ are positive. The causal link from ‘Work remaining’ to ‘EAC’ is positive. When EAC increases, it increases VAC. So, the causal link from ‘EAC’ to ‘VAC’ is positive. The feedback loop formed by the four positive links will be a positive loop.
Fig. 5.4.2.1(f). SD feedback loops in the system of 'Earned value analysis'
5.4.2.2. Causal loop model of the system of ‘Earned value analysis’

With the help of the entire feedback loops explained earlier, the complete causal loop model of the system of ‘Earned value analysis’ has been developed and is diagrammatically shown in the figure, Fig. 5.4.2.2.
5.4.2.3. Stock and flow model of the system of 'Earned value analysis'

BCWS and ACWP have been treated as level variables and the four variables, namely, 'Cost adding rate', 'BAC', 'Actual cost' and 'EAC' as rate variables. Two adjustment factors, namely, one 'Adjustment factor' for 'Cost adding rate' variable and second 'Performed work adjustment' factor for both BCWP and 'Actual cost' have been introduced into the causal loop diagram to validate the initial conditions of those variables with the real data. This way, a detailed stock and flow model has been developed and is shown in the figure, Fig. 5.4.2.3.
5.4.2.3. A Case study

A real-world case study was conducted in India during 1997-98 in one public IT organization, which had sub-contracted a project to a private software development company through tendering process. The aim of the project was to develop software to enable the people (or users) to view the information on budget distributed among different heads, sub-heads and accounts. The software company submitted their final project proposal and got the contract signed. According to the contract, the total project cost was mentioned as Rs. 5,40,000/- with the cost of unit effort (in the present case, a person-day) as Rs. 225/- and the total project duration was 10 (tee) months. It was found that the number of person-months quoted by the company was around 100 and the total number of people planned to be
deployed for the project was 10. It was also found that there are many work-packages to be distributed among different groups of developers and the average effort for one work package was around 60 person-days. As per the contract, the respective officers of the user organization regularly monitored the progress of the project and evaluated the outcomes from time to time at different stages of the project.

The above data of the project has been used in the system dynamics stock and flow model developed for the system of earned value analysis and the simulation results have been correlated to the various trends that were observed during the development of project. The simulation results are quite agreeing with the experiences of the real project and validating the SD models thus developed for the system of earned value analysis.

5.4.2.5. Modelling equations for the system of ‘Earned value analysis’

The modeling equations, as given in the Table 5.4.2.5, have been fed to the respective variables of the stock and flow model of the system of earned value analysis for simulation purpose. Following the case study, the total duration for the activity of monitoring the project has been assumed as 10 months, with the total project cost as Rs. 5,40,000/-, estimated cost of unit effort as Rs. 225/-, and average estimated effort for work package as 60 person-days.

The delay has been assumed as nil (that is, without any delay in the project) and the ‘performed work adjustment’ as 0.3944. The ‘adjustment factor’ for cost adding rate and BCWP has been assumed as 2.50771 to enable the model generate the same final values for BCWS, BCWP and ACWP, that is, Rs. 5,40,000/- as quoted by the software company in the case study.

Actual cost has been equated to ACWP plus the product of the estimated cost of unit effort and the sum of delay time and performed work adjustment, whereas ACWP has been equated to the integration of actual cost with unit initial value. Estimated cost of work package has been equated to the product of estimated effort for work package and estimated
cost of unit effort. The variable, ‘Cost adding rate’ has been equated to the ratio between the sum of estimated cost of work package and BCWS, and adjustment factor. BCWS has been equated to the integration of cost adding rate with an initial value of 100.

BCWP has been equated to the product of BCWS and an expression of 1 minus the product of delay time, performed work adjustment and estimated effort for work package. BAC has been equated to BCWS and ‘Work remaining’ equated to the difference between BAC and BCWP. EAC has been assigned to the sum of ACWP and the product of work remaining and estimated cost of unit effort.

All the other remaining variables have been assigned the respective expressions as given in their definitions.

**Table 5.4.2.5. SD modeling equations for the system of ‘Earned value analysis’**

| (i) | INITIAL TIME = 0.25 | (The initial time for the simulation) |
| (ii) | FINAL TIME = 10 | (The final time for the simulation). |
| (iii) | TIME STEP = 0.25 | (The time step for the simulation). |
| (iv) | SAVEPER = TIME STEP | (The frequency with which output is stored). |

(1) Estimated cost of unit effort = 225.
(2) Estimated effort for work package = 60.
(3) Delay time = 0.
(4) Performed work adjustment = 0.3944.
(5) Adjustment factor = 2.50771.
(6) Actual cost = (Delay time + Performed work adjustment) * Estimated cost of unit effort + ACWP.
(7) ACWP = INTEG (Actual cost, 1)
(8) Estimated cost of work package = Estimated effort for work package * Estimated cost of unit effort.

(Contd….)
(9) Cost adding rate = (Estimated cost of work package + BCWS) / Adjustment factor
(10) BCWS = INTEG (Cost adding rate, 100).
(11) BAC = BCWS.
(12) BCWP = BCWS * (1 - Delay time * Performed work adjustment * Estimated effort for work package).
(13) Work remaining = BAC - BCWP.
(14) EAC = ACWP + Work remaining * Estimated cost of unit effort.
(15) CPI = BCWP/ACWP.
(16) CV = BCWP - ACWP.
(17) ETC = Work remaining/CPI.
(18) FAC = ACWP + ETC.
(19) SPI = BCWP/BCWS.
(20) SV = BCWP - BCWS.
(21) VAC = BAC - EAC.

5.4.2.6. Simulation results of the system of ‘Earned value analysis’

Different patterns of behaviour have been observed prominently in some variables as shown in the figures, Fig. 5.4.2.6(i) and Fig. 5.4.2.6(ii).

It is observed from the simulation results that due to different patterns of growth in BCWP and ACWP, the cost variance, (CV) slowly raised and reaches a peak value of nearly Rs. 1,50,000/- and then started to decay exponentially by reaching zero value by the final time. Similar trend is observed in the variable VAC. The cost performance index (CPI = BCWP/ACWP) started to decrease steeply in the beginning for a while and then smoothly by reaching zero value finally.
Fig. 5.4.2.6(i). Patterns of behaviour in the system of 'Earned value analysis'

**CV**

- 200,000
- 149,995
- 99,990
- 49,985
- -20

**ACWP**

- 600,000
- 450,000
- 300,000
- 150,000
- 0

**BCWP**

- 600,000
- 450,000
- 300,000
- 150,000
- 0

**BCWS**

- 600,000
- 450,000
- 300,000
- 150,000
- 0

**BAC**

- 600,000
- 300,000
- 0

Time (Month)

0 1 2 3 4 5 6 7 8 9 10
5.4.2.7. Sensitivity analysis results of the system of ‘Earned value analysis’

Sensitivity analysis of the simulation of SD model of ‘Earned value analysis’ has been carried out separately for each of the following three types of variations:
1) Variation of value of 'Estimated cost of unit effort' from its initial value of 225 to 330, that is, increasing the estimated cost of unit effort by nearly 45%.

2) Variation of value of 'Delay time' from its initial value of 0 to 0.25, that is, adding delay of 25% of the project duration; and

3) Variation of value of 'Estimated effort for work package' from its initial value of 60 to 100, that is, increasing the average effort for work package by nearly 65%.

During variation of one of the above three variables, the other two variables have been kept at their initial values. In all the graphs of sensitivity analysis, graph I (red colour) represents the pattern of initial behaviour and graph II (blue colour) represents the behaviour resulted from sensitivity analysis.

(i) When estimated cost of unit effort is increased from 225 to 330, all the three important variables, BCWS, BCWP and ACWP also increased based on the increase in the cost of unit effort. This result produced proportionate changes in the earlier initial behaviour of all other remaining variables. This sensitivity analysis is represented in the figure. Fig. 5.4.2.7(i)a and Fig.5.4.2.7(i)b.

The sensitivity analysis report validates the usual experience in projects, that is, any increase in the estimated cost of unit effort affects all the related budget items, especially, it increases BCWS, BCWP and ACWP, which in turn change the other elements that depend on them.
Fig. 5.4.2.7(i)a. Sensitivity analysis (changing estimated cost of unit effort) of 'Earned value analysis'.

- BCWP
- BCWS
- CV
- ACWP

Time (Month)
(ii) When the delay time is increased from 0 to 0.25, that means the project is delayed leading to more pending work, the variable ‘Work remaining’ increased exponentially from its initial value of zero (nil). As delay increases, the work performed will become less and hence BCWP will decrease. When an activity is delayed, its duration increases and consumes more money for its execution and hence ACWP increases more. In the case study, it was observed that when some work packages were delayed, the payment installments were also delayed by the user organization to the software development company. Due to this, the software company might have faced financial problems internally resulting decrease in budgeted cost and increase in the actual cost for the work performed for any time duration. These opposite patterns of behaviour observed in BCWP and ACWP resulted exponential decay in the cost variance (CV). With the delay, schedule variance (SV) decays exponentially from its initial steady value of zero (when
BCWP = BCWS). Similar decay pattern is observed in the case of VAC. Fig. 5.4.2.7(ii)a and Fig.5.4.2.7(ii)b show the patterns of behavior of different variables.

Fig. 5.4.2.7(ii)a. Sensitivity analysis (changing delay time) of ‘Earned value analysis’
(iii) When the estimated effort for work package is increased from 60 to 100, the effort of the total project increases. Due to this change, BCWS and BCWP also increased proportionately from their initial values. As ACWP depends on the amount of work performed so far and the cost incurred therein, irrespective of how much the total project effort is, there should be no change in the behaviour of ACWP and the same trend is observed from the simulation results. As ACWP does not change and BCWP goes on increasing, the resulting cost variance increases proportionally. All these trends in the
behaviour of different variables are clearly shown in the figures, Fig. 5.4.2.7(iii)a and Fig.5.4.2.7(iii)b.

*Fig. 5.4.2.7(iii)a. Sensitivity analysis (changing estimated effort for work package) of*

*Earned value analysis*
Fig. 5.4.2.7(iii)b. Sensitivity analysis (changing estimated effort for work package) of ‘Earned value analysis’

All the sensitivity analysis results of the system of ‘Earned value analysis’ are well validating the trends that can be predicted or experienced in the real projects.
5.5. PROJECT CONTROL

Measurement and evaluation of project performance requires a control process. The purpose of project control is to bring the actual schedule, budget and deliverables of the project into reasonably close congruence with the planned schedule, budget and deliverables (Meredith and Mantel 2003). Project control uses the data supplied by monitoring process to identify and control different issues of project. Once the initial project plan has been published, project control should deal those things that are deviating from the planned track. Project control is a continual process of monitoring progress against the plan and, where necessary, revising the plan to take account of deviations (Hughes and Cotterell 200). An effective mechanism for controlling projects under development must provide review points to enable project managers continually to monitor and assess progress, performance, and budget status, wherever necessary, re-evaluate, reschedule, or even terminate the development work. When there is a mismatch between the planned outcomes and the actual ones, then either re-planning is needed to bring the project back on target or the target will have to be revised.

The control process generally consists of many issues like setting a baseline plan, measuring progress and performance, comparing plan against actual things happening, taking appropriate action, etc. Baseline plan provides the elements for measuring performance of the project. The baseline is derived from the cost and duration information found in the work breakdown structure (WBS) and time-sequence data from the resource allocation and scheduling. Qualitative measures such as meeting customer technical specifications and product functions are most frequently determined by on-site inspection or actual use. Control may also be applied on human elements like frustration, pleasure, determination, hopelessness, anger, and many other emotions that arise during the course of a project.

Project quality is the totality of features and characteristics of a product or services that bear on its ability to satisfy specified or implied needs. The project manager has the ultimate responsibility for quality management because the quality management has equal priority with cost and schedule management. When the project is controlled in different issues from its start, the quality will be automatically improved in different stages of project development.
It is essential for effective project control that performance is measured while there is still time to take corrective action (Burke 2000). According to Cadle and Yeates (2001), the possible corrective actions, that might be considered to control an Information Systems (IS) project, are literally endless. They listed most common project management responses to problems encountered on IS projects as (1) adding more staff for activities lagging behind schedule, (2) adding different skills as an alternative to adding more staff by adding people with different or greater skills, (3) using overtime, which is the cheapest way of buying additional effort, (4) reassigning tasks among the existing project team without adding any new one, (5) increasing/decreasing individual supervision depending on the progress of the project, (6) finding improved methods of working, (7) streamlining the procedures, (8) re-planning the project, (9) changing the phases of deliverables, (10) subcontracting some parts of the work, (11) negotiating changes in the specification, etc. All these issues were also evident from the surveys performed by the author.

Periodic monitoring and measuring the status of the project allow for comparisons of actual versus expected plans. Frequent status reports allow for early detection of variations from plan and early correction of causes. Usually status reports should take place as frequently as possible to be useful and allow for proactive correction.

According to Hughes and Cotterell (2002), the original plans for project are almost certain to be changed before the project is completed. The most common changes to the project are requested either by the client or the project team members to try to improve the product or service. Due to these changes, either the process or the output of a project may be changed and this leads to change in the budget and/or schedule. From most IT departments of organizations surveyed, it was expressed by the managers that at least 20% of any software project undergoes changes due to various reasons and one of their important responsibilities is to implement and manage such changes in the project.

In IT projects, configuration management (CM) is a key management tool used in controlling the projects and their assets. It directs and controls the development of a product by identification of the product components and control of their continuous changes. It
ensures that at any given time the status of each product is known and provides information on the project status history so that project audit trails can be carried out. It helps in carrying out design changes, corrections and enhancements in a controlled manner. The scope of work defines what the project is producing or delivering and the control of the scope of work is nothing but configuration management (Cadle and Yeates 2001).

Based on the above discussion, the salient variables that influence the system of 'Project Control' have been identified and listed in Table 5.5.

<table>
<thead>
<tr>
<th>Table 5.5. List of salient variables in the system of 'Project Control'</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Salient variables</strong></td>
</tr>
<tr>
<td>1. Defects</td>
</tr>
<tr>
<td>2. Change request</td>
</tr>
<tr>
<td>3. Configuration management</td>
</tr>
<tr>
<td>4. Corrective actions</td>
</tr>
<tr>
<td>5. System tests</td>
</tr>
<tr>
<td>6. Deviation from plan</td>
</tr>
<tr>
<td>7. Project monitoring</td>
</tr>
<tr>
<td>8. Project progress</td>
</tr>
<tr>
<td>9. Project Control</td>
</tr>
</tbody>
</table>

5.5.1. Basic SD feedback loops in the system of 'Project Control'

Based on the influences among different salient variables identified, seven different feedback loops have been formed and are shown in Figure 5.5.1. The analysis of feedback loops is as follows:

(a) Project monitoring provides the information on the status of project and by this the project team will have clear idea about where to apply control to remove hurdles to the progress of project. Hence, the causal links connecting the variable 'Project monitoring' to the two variables 'Project Control' and 'Project progress' have been treated as positive
links. When project control is applied effectively, the progress of the project will be improved and hence, the causal link from ‘Project Control’ to ‘Project progress’ has been assigned positive sign. The feedback loop formed by these three positive causal links will be a positive feedback loop.

(b) Project control is aimed to bring actual performance of the project into approximate congruence with planned performance and hence the increase in project control reduces the deviation between the planned performance and the actual performance. Therefore, the causal link between ‘Project Control’ and ‘Deviation from plan’ has been treated as a negative link. Taking appropriate corrective actions leads to effective control on the project and also reduces deviation of project from plan. Hence the causal link from the variable ‘Corrective actions’ to ‘Project Control’ has been treated as positive link and that to ‘Deviation from plan’ as negative link. The feedback loop formed by these three causal links will be a positive loop, because of the presence of even (two) number of negative links.

(c) Increase of defects leads to increase in the deviation of project from plan. Taking corrective actions reduces the defects and the deviation from plan. Hence the causal link from ‘Defects’ to ‘Deviation from plan’ has been treated as positive link and those links from ‘Corrective actions’ to the two variables ‘Defects’ and ‘Deviation from plan’ treated as negative links. The feedback loop formed by these links will be a positive loop.

(d) Increase of change requests hampers the progress of project and demands more system tests to check whether they have been implemented properly or not. More number of system tests demands more monitoring. Hence the causal link between ‘Change requests’ and ‘Project progress’ has been treated as negative, that between ‘Change requests’ and ‘System tests’ as positive and the link from ‘System tests’ to ‘Project monitoring’ as positive link. Improved project monitoring leads to improvement of progress in project and hence the causal link between ‘Project monitoring’ and ‘Project progress’ will be a positive link. The feedback loop formed by these three positive and one negative causal links will become a negative loop.
(e) Increase in system tests and change requests demands increase in project monitoring for checking their effective implementation. Hence the causal links from the variables, ‘System tests’ and ‘Change requests’ to ‘Project monitoring’ have been treated as positive links. The causal link from ‘Change requests’ to ‘System tests’ is also positive. The feedback loop formed by these three positive causal links will also be positive.

(f) Taking more corrective actions improves control on the project and demands more monitoring to check whether the corrective actions have been implemented properly. Hence the causal links from the variable ‘Corrective actions’ to the two variables ‘Project Control’ and ‘Project monitoring’ will be positive. The causal link between ‘Project monitoring’ and ‘Project Control’ is also positive. The feedback loop formed by these three positive causal links will also be positive.

(g) Increase of change requests and defects in the project makes the project deviate more from plan. Hence the causal links from the two variables ‘Change requests’ and ‘Defects’ connecting to the variable ‘Deviation from plan’ have been treated as positive links. Increase in change requests and corrective actions demands more monitoring activity in order to check their successful implementation and hence the causal links from the two variables ‘Change requests’ and ‘Corrective actions’ connecting to ‘Project monitoring’ have been treated as positive links. Taking more corrective actions reduces the defects and hence the causal link between ‘Corrective actions’ and ‘Defects’ has been treated as a negative link. The feedback loop formed by these five causal links will be a negative loop because of the presence of odd (one) number of causal links.
5.5.2. Causal loop model of the system of ‘Project Control’

The more the configuration management, the more will be the control on project, because configuration management ensures that, if the changes are implemented, then amendments to each of the effected deliverables are properly controlled and recorded. Hence the causal link from the variable ‘Configuration management’ connecting to ‘Project Control’ has been treated as a positive link.
With the help of this positive causal link and the seven feedback loops discussed earlier, the causal loop model of the system of project control has been developed and is shown in Figure 5.5.2.

Figure 5.5.2. Causal loop model of 'Project Control'

5.5.3. Stock and flow model of the system of 'Project Control'

With the help of causal loop model of the system of project control, its equivalent stock and flow model has been developed and is shown in Figure 5.6.3. The variable 'Project Control' has been treated as 'stock' (or 'level') and the variables 'Project progress' and 'Deviation from plan' as flow rates, because the rate of progress of project and other connected variables improve the level of project control from where the deviations will be thrown out.
5.5.3. Stock and Flow model of 'Project Control'

5.5.4. Modeling equations for the system of 'Project Control'

For simulation activity, the modeling equations, as given in the Table 5.6.4, have been fed to the respective variables of the stock and flow model of the system of project control. The project duration has been assumed as 1 year, that is, 12 months with a time step of 0.25 (3 months).

Based on the feedback of most IT departments of the organizations surveyed that at least 20% of any software project undergoes changes due to various reasons, the variable 'Change requests' has been assigned a value of 0.2. The 'Corrective actions' has been assumed as 0.1 (that is, 10%) and the 'Configuration management' initiated with nil (0) value.

The variable 'Defects' has been equated to the reciprocal of the sum of corrective actions and unity. Assuming that the activity of system testing is routine (100%, that is 1) and it
increases with the increase of change requests, the expression for the variable 'System tests' has been written as adding unity (1) to the value of 'Change requests'. 'Deviation from plan' has been equated to the ratio between exponential of the sum of change requests and defects and the sum of corrective actions and project control. Project control has been equated to the integration of the product of project monitoring and corrective actions plus configuration management with an initial value of zero (0).

Project monitoring has been equated to change requests plus sum of unity (1) and the product of corrective actions and system tests. Project progress has been equated to the product of project monitoring, project control and a numeral 10 divided by change requests.

Table 5.5.4. SD modeling equations of the system of ‘Project Control’

(i) INITIAL TIME = 0 (The initial time for the simulation).
(ii) FINAL TIME = 12 (The final time for the simulation).
(iii) TIME STEP = 0.25 (The time step for the simulation).
(iv) SAVEPER = TIME STEP (The frequency with which output is stored).

(1) Change requests = 0.2.
(2) Configuration management = 0.
(3) Corrective actions = 0.1.
(4) Defects = 1/(1+Corrective actions).
(5) System tests = 1+Change requests.
(6) Deviation from plan = EXP(Change requests + Defects) / (Corrective actions + Project Control).
(7) Project Control = INTEG ((Project monitoring * Corrective actions) + Configuration management, 0).
(8) Project monitoring = Change requests + (1 + Corrective actions * System tests)
(9) Project progress = 10 * (Project monitoring * Project Control) / Change requests.
5.5.5. Simulation results of the system of ‘Project Control’

Using the modeling equations and the initial set of values of the variables, the stock and flow model of the system of project control has been simulated. The simulation results observed in important variables are shown in Figure 5.5.5. Growth behaviour is observed in the two variables ‘Project progress’ and ‘Project Control’, whereas decay behaviour observed in the variable ‘Deviation from plan’. This result is supporting the usual observation in projects, that when project control is increased the project runs in good progress by reducing deviations from plan.

*Figure 5.5.5. Patterns of behaviour in the system of ‘Project Control’*

![Graph showing patterns of behaviour in the system of 'Project Control' with axes for Project progress, Project Control, and Deviation from plan against time in months.](image)
5.5.6. Sensitivity analysis results of the system of ‘Project Control’

To validate the system dynamics model of project control, a sensitivity analysis has been carried out by changing the values of the three important variables, namely, ‘Change requests’, ‘Corrective actions’ and ‘Configuration management’ and observing the behaviour in the variables ‘Project progress’ and ‘Project Control’. The sensitivity analysis results are shown in the figures, Fig. 5.5.6(i), (ii) and (iii) respectively. In each figure, for comparison purpose, the initial behaviour of the system has been represented by graph I (red colour).

(i) When the value of the variable ‘Change requests’ is decreased from its initial value of 0.2 (20%) to 0.1 (10%), graph II (green colour) of Figure 5.5.6(i) resulted. When its value is increased from 0.2 to 0.5, graph III (blue colour) of Fig. 5.5.6(i) resulted. From these results, it is observed that reduction of change requests is increasing project progress further and reducing project control, because reduction in the number of change requests results in reduction of control. But the decay behaviour of deviation from plan started at further low value near 27, when compared with the value of 30 resulted from the initial simulation run. When the value of ‘Change requests’ is increased from its initial value of 0.2 to 0.5 (50%), more decay is observed in the project progress, whereas more growth observed in project control due to necessity of more control. Decay behaviour of ‘Deviation from plan’ started at a higher value above 40 when compared with that of initial simulation run (i.e., 30). This pattern of behaviour has been represented by graph III of Figure 5.5.6(i).

In all the organizations surveyed, it was expressed by the managers of IT projects that the requests to add or delete some items in the project delayed the total project, and in some cases the delay was severe. All these changes are new and not existing in the actual project plan. In APTS, a software development project of a state government’s corporation was given to a private software development company by tendering process. The company aggressively and systematically started developing the project, but delayed it badly due to continuous changes requested by the user organization. Even though the project was survived from such continuous changes, a directive from the central government federation to change the development platform of the software application from Delphi software to Visual Basic software frustrated the software developer a lot.
(ii) When the value of the variable, 'Corrective actions' is increased from its initial value of 0.1 (10%) to 0.2 (20%), that is, doubled, a high growth behaviour is observed in 'Project progress' and 'Project Control', supporting the fact that the more the corrective actions taken the more will be the progress and control in the project. The decay behaviour of 'Deviation from plan' started at a very low value below 20. These patterns of behaviour are represented by the graph II in Figure 5.5.6(ii). When the value of 'Corrective actions' is decreased from its initial value of 0.1 to 0.05 (5%), that is, halved, high decay is observed in 'Project Control' and 'Project progress' as well and a very high growth observed in 'Deviation from plan'. This pattern of behaviour is represented by graph III of Figure 5.5.6(ii). These results are supporting the fact that reduction of corrective actions reduces the progress and control in the project and thereby increases the deviation of the project from plan.
of behavior become considerably high, as shown by the graph II in Figure 5.6(!!!). When configuration management is increased to 0.1 (10%), the above patterns continue; whereas further decay occurred in the decay behavior of deviation from control, and whereas further growth occurred in the increased behavior of deviation, and Project Control, as shown behavior in project projects. Project Control of deviation when the value of configuration management is increased slowly from its initial value.

\[ \text{Time (in months)} \]

\[ \text{Deviation from plan} \]

\[ \text{Project Control} \]

\[ \text{Project progress} \]

\[ \text{FIG. 5.6(!!!)} \] Sensitivity graph of Project Control.

Project Control: The more the quality in the project the more will be the progress in the project. The more the quality in the project the more will be the progress in the project. The activity of configuration actions is very important to improve the quality of project and it demands considerable thoroughness and hence more control on the project is required. The activity of configuration actions has on other items and modules of the project should be checked to lead the project meeting the objectives. While making the conclusions, the results and errors arise from changes made in the project or defects in written the code or ensuring the

237
This result is supporting the fact that configuration management is a good project control technique to lead the project in good progress by further reducing the deviations from plan.

*Fig. 5.5.6(iii). Sensitivity analysis of ‘Project Control’*

From the above results, it is evident that the variables ‘Change requests’ and ‘Corrective actions’ are showing high influence on the system of project control when compared with ‘Configuration management’. Similar thing has been expressed by the managers of most of the IT companies surveyed. In APTS, the old and new versions of every software application will be stored separately in the server systems of system administration department. Whenever any application is to be customized for the use of another user, it will be easy to take the old version of application and make necessary changes. The configuration management demands control on the project in order to store, update and maintain different configurations of the same project.