Applying System Dynamics Principles to CDEEP System

M.Tech. Project Report

Submitted in partial fulfillment of the requirements of the degree of

Master of Technology

by

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Declaration

I declare that this written submission represent my ideas in my own words and where others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can evoke penal action from the sources which has thus not been properly cited or from whom proper permission has not been taken when needed.

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Abstract

Distance education is being seen as a cost effective alternative of conventional classroom education. IIT Bombay had started the Centre for Distance Engineering Education Programme (CDEEP) for providing high quality distance education in engineering and science to a large number of students throughout the country. It is providing distance education through live transmission of IIT courses, through satellite and webcast. This initiative is acting as a helping hand to improve the degrading state of engineering education in India. This report attempts to model CDEEP system using System Dynamics, a well known system modeling approach. It analyzes various feedback loops in the system that cause dynamic changes in the behaviour of the system. It also makes policy recommendations for refining the structure of the system, which in turn could improve the behaviour of the system.

Contents

Chapter 1

Introduction

According to the All India Council for Technical Education, India produced 401,791 engineers in 2003-04 and in 2004-05, the number of engineering graduates increased to 464,743[9]. Currently there are more than 500,000 students pursuing engineering education in around 3200 colleges over the country. Apart from the top institutes like IITs, the overall quality of the engineering education in India is very poor and needs to be improved significantly. According to a McKinsey Global Institute study, only 25 per cent of our engineering students are employable[9]. The main reason behind this is the lack of well qualified teachers. Because of IT boom and rapid development of the Indian economy, high salary jobs are now easily available for qualified engineers, but salaries for teachers of higher educational institutes have not increased in that proportion to attract qualified people in this field. As a result, most of the institutes are lacking well qualified teachers and hence are not able to produce competitive engineers.

Distance education is seen as a cheaper and effective solution to ensure the availability of high quality engineering education for the students all over the country. It has a very important role to play in the context of scarcity of resources in developing countries, like India. With the recent trend of technological advancement, distance education is being recognized for its potential in providing individual attention and communication with students. IITB with Ministry of Human Resource Development(MHRD) had started Centre for Distance Engineering Education Programme (CDEEP) aiming to make available the good quality courses taught by IIT Bombay faculty to the students and working professionals everywhere in the country[10] .

CDEEP has been quite successful in achieving its goal of ensuring availability of the quality education everywhere in the country. Still the number of students taking benefit from CDEEP has not increased with the rate at which number of engineering students has increased during last decade. We are attempting to address this problem using System Dynamics techniques, which has been extensively used in modeling complex feedback systems in a wide range of areas, for example population, ecological and economic systems. We are trying to build a model of CDEEP system and to suggest the changes in the existing system to improve it.

1.1 About CDEEP Program

Started in 2003 by IIT Bombay, CDEEPs mission is to make IIT courses available to all the students in India and around the world[9]. CDEEP gives all students the facility of studying at any time, at any place and at their own place. To achieve this, currently it is involved in three modes of dissemination:

- Live transmission through Internet known as webcast: Currently CDEEP has 4 studios in IIT campus,[1] from where courses are recorded and transmitted live and free of cost over the internet through webcast at 100 Kbps bandwidth since January, 2008. Anyone, sitting anywhere in the world, needs only a PC and 100kbps internet bandwidth to access it.

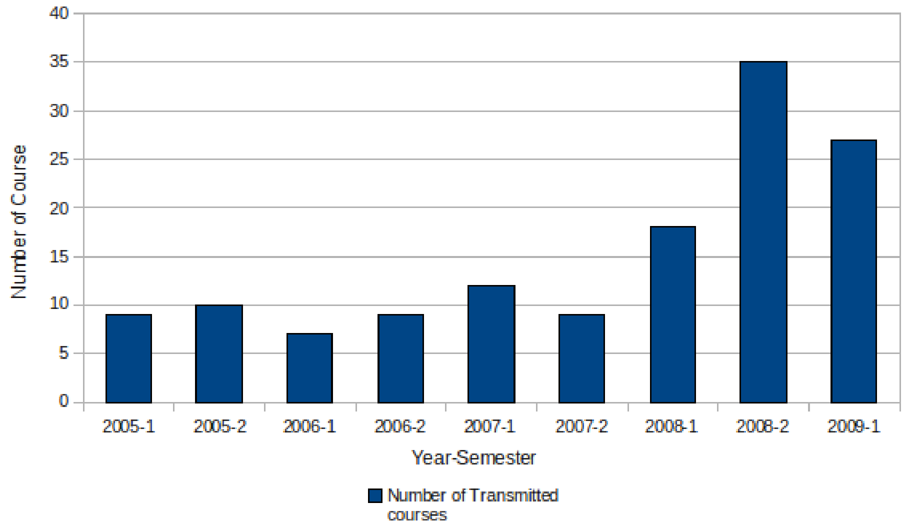

Figure 1.1: Total number of courses per semester

- Live transmission through satellite: It simulates a classroom environment of IIT Bombay and provides high quality education to a large number of participants through various remote centers (RCs). organizations. Through satellite terminals each RC establishes a two way interactive environment with studio at IIT Bombay, from where, the lectures are delivered. The satellite broadcast is done through EDUSAT satellite. Currently there are 72 Remote Centers across the country which take advantage of this educational program. These remote centres are generally other engineering institutes who want their students to take IITB's course through live transmission. To become IIT Bombays remote center, it is necessary to first install a Student Interactive Terminal (SIT) of ISRO (Indian Space Research Organization) in a classroom so that EDUSAT-transmitted courses can be received in the institute, Once an SIT is installed at that institution, then it can receive totally free of cost all the courses transmitted through EDUSAT from IIT Bombay. Students can also interact live with IIT Bombay instructors.
  Currently out of the 4 studios available at IITB for recording only 1 studio has a link to the Indian Space Research Organization (ISRO) satellite EDUSAT; courses recorded in that studio are transmitted through the satellite as well. Fig 1.1 shows number of course transmitted since year 2005.

- Video recording of class room lectures and important seminars and making them available on media (Video on Demand). This mode is specially beneficial for IITB students, as they can view the same lectures while preparing for their exams.

1.2 Organization of Report

The rest of the thesis is organized as: Chapter 2 starts with a brief introduction of system dynamics modeling approach and its applications. In addition to this, causal-loop diagrams and stock-flow diagrams are also discussed. In Chapter 3, we start with preparing initial webcast model, and later improve it into modified webcast model. Both these models are simulated for different scenarios and the results are discussed. Chapter 4 models and analyzes EDUSAT system of CDEEP program. Various simulations are performed considering different scenarios. Chapter 5 discusses about opensource simulators available for system dynamics modeling and explains the idea of System Dynamics Information Model. Chapter 6 gives a concluding summary and ideas about future work which can be done as a continuation to this project.

Chapter 2

System Dynamics Basics

The basic viewpoint of system dynamics requires that we first define a 'system'. Simplest definition is that, a 'system' is a collection of parts which interact in such a way that the whole has properties which are not evident from the parts themselves.

When an event in the system influences its own behaviour in future, such a situation is called a feedback loop or causal loop. Identifying and analysing the feedback loops is one key concept of system dynamics. It deals with internal loops and time delays that affect the behaviour of the entire system. It looks at every system as a system made up of interacting parts, and believes that behaviour of the whole cannot be explained in terms of the behaviour of the parts. System dynamics uses computer simulations for understanding, and analysing complex systems.

System dynamics is an approach to understand the behaviour of complex systems over time.[2] Basic System Dynamics Modeling process of any feedback system can be summarized in following points [8] :

- Identify the problem. Define system boundaries and identify its individual components (also called variables) which determine system's behaviour.

- Create a basic influence diagram, also known as causal loop diagram (discussed in section 2.2), representing cause-effect relation between different variable .

- Convert the causal loop diagram to a Stock-flow diagram (discussed in section 2.3). This diagram distinguishes variables between stock and flow.

- Write the equations that determine the flows, and estimate initial conditions for stocks (discussed in section 2.3.1). These can be estimated using statistical methods, expert opinion, market research data or other relevant sources of information.

- Simulate the model and analyse results.

We will be explaining the feedback loops structures, Causal loop diagrams and Stock flow diagrams in the subsequent sections, as they are the building blocks of understanding the system dynamics modeling process.

2.1 Feedback Structure and Graphical Representation of a model

As discussed earlier, when an event in the system influences its own behaviour in future, such situation is called a feedback loop or causal loop. Feedback loops are the most important part of the study of system dynamics. Depending on their impact on the behaviour of the system, we can categorize feedback loops in positive or negative feedback loops. We will be discussing these loops using causal loop diagram and stock-flow diagram in next section.

Causal Loop Diagram (CLD) and Stock and Flow Diagram (SFD) are used to represent the feedback structure of the system. These are the graphical representation of system as composed of different components or variables and their relation with one another. This relation defines the way one variable affects the other.

2.2 Causal Loop Diagram (CLD)

A causal-loop diagram consists of a set of nodes representing the variables connected together through cause and effect relationships. The relationship between the variables is represented by arrows (called causal links). An arrow from a variable $\boldsymbol{a}$ to another variable $\boldsymbol{b}$ represents that any change in variable **a** will eventually affect variable **b**. **a** is called the *cause* and b the *effect*. Depending upon the relation between cause and effect the arrow can be labeled as positive or negative.

- **Positive causal link** (represented by a + sign on the link) mean that if *cause* increases the *effect* increases and if *cause* decreases the *effect* will also decrease.

- **Negative causal link** (represented by a $-$ sign on the link) mean that if *cause* decreases the *effect* increases and if *cause* decreases the effect will increase.

A feedback loop can be easily identified in the system by searching a cycle or loop in the CLD. In CLD a complete loop is also given a sign. The sign for a particular loop is determined by counting the number of minus ($-$) signs on all the links that make up the loop.

- **Positive (Reinforcing) Feedback Loop** A feedback loop is called positive, indicated by a +sign in between the loop, if it contains an even number of negative causal links. A positive, or reinforcing, feedback loop reinforces change with even more change. This can lead to rapid growth at an ever-increasing rate. This type of growth pattern is often referred to as exponential growth. In the early stages of the growth, it seems to be slow, but then it speeds up.

- **Negative (Balancing) Feedback Loop** A feedback loop is called negative, indicated by a $-$ sign in between the loop, if it contains an odd number of negative causal links. A negative, or balancing, feedback loop seeks a goal. If the current level of the variable is above the goal, then the loop structure pushes its value down, while if the current level is below the goal, the loop structure pushes its value up.

- **Negative Feedback Loop with Delay** A negative feedback loop with a substantial delay can lead to oscillation. The specific behaviour depends on the characteristics of the particular loop. In some cases, the value of a variable continues to oscillate indefinitely, as shown above. In other cases, the amplitude of the oscillations will gradually decrease, and the variable of interest will settle toward a goal.

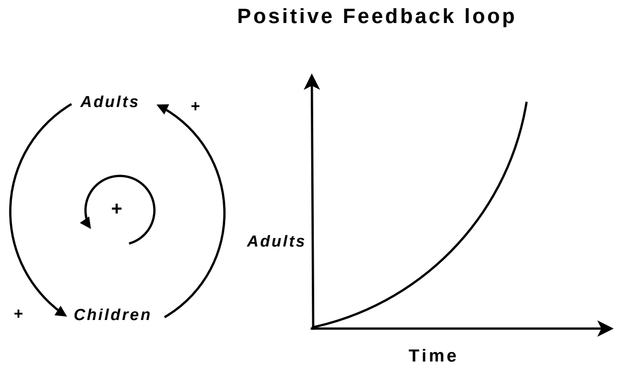

Figure 2.1: Positive feedback loop

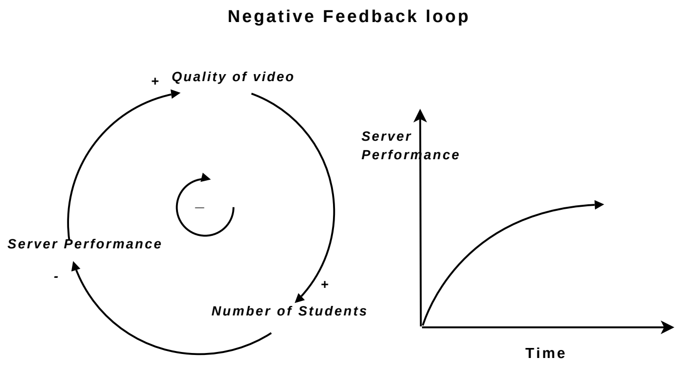

Figure 2.2: Negative feedback loop

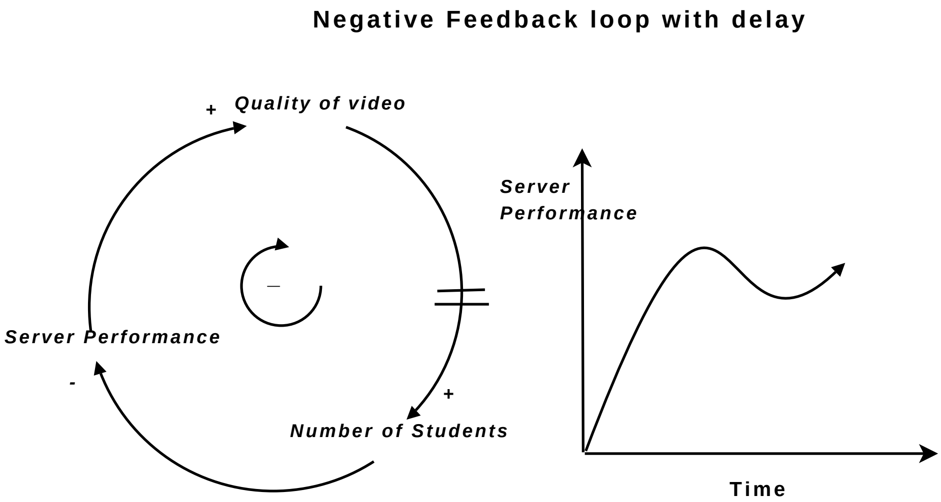

Figure 2.3: Negative feedback loop with delay

- **Combination of Positive and Negative Loops** When positive and negative loops are combined, a variety of patterns are possible. The example in fig 2.4 shows a situation where a positive feedback loop leads to early exponential growth, but then, after a delay, a negative feedback loop comes to dominate the behaviour of the system. This combination results in an s-shaped pattern because the positive feedback loop leads to initial exponential growth, and then when the negative feedback loop takes over it leads to goal seeking behaviour.

2.3 Stock Flow Diagram (SFD)

As with a causal loop diagram, the stock-flow diagram shows relationships among variables which have the potential to change over time. The SFD consists of three different types of elements: stocks, flows, and information. Unlike a causal loop diagram, a stock-flow diagram distinguishes between different types of variables.
A **stock** (or "level variable") is some entity that is accumulated over time by inflows and/or depleted by outflows. Stocks can only be changed via flows. Mathematically a stock can be seen as an accumulation or integration of flows over time - with outflows subtracting from the

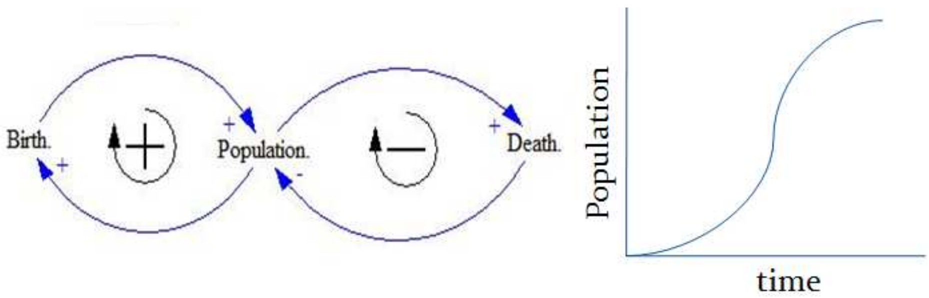

Figure 2.4: Combination of Positive and Negative feedback loops

stock. Stocks typically have a certain value at each moment of time - e.g. the number of students viewing the CDEEP videos at a certain moment.
A **flow** (or "rate") changes a stock over time. Usually we can clearly distinguish inflows (adding to the stock) and outflows (subtracting from the stock). Flows typically are measured over a certain interval of time e. g. the number of joining CDEEP over a day or month.
The last element in the stock-flow diagram is the **information link** shown by the curved arrow. This arrow means that in some way information about the value of one variable influences the value of other one. This can considered same as **causal link** in CLD.

2.3.1 Equations

Stock-flow diagrams are only graphical representations of the system, alone they are not able giving any useful insight about the system. To be able to reason and analyse the behaviour of the system we need to quantify its variables and also the relation between its variables also need to be defined mathematically[3] . SFD allows us to represent the relations among variables in terms of differential or integral equations.
For example, the number of students at any time instance t is equal to the number of students at the starting time plus the number of students that joined in minus the number that has left. If inflow and outflow is measured in students per unit time, and let their values are i and o respectively, then

$$\# \ of \ students = Initially(\# \ of \ students) + \int_0^T (inflow - outflow)\, dt \tag{2.1}$$

It quickly becomes infeasible to solve such equations by hand as the number of stocks and flows increases in the system, or if the equations for the stocks are more complex than those shown in above equation. Thus, computer solution methods are used most of the times.

2.4 Simulation

There are many commercial software packages such as VenSim, Stella, PowerSim available in the market for preparing and simulating system dynamics models. With these packages, as with most PC-based system dynamics simulation systems, we can start by entering a stock and flow diagram for the model. We then need to enter the initial values for the various stocks into the model, and also the equations for the flows. Once this is done, we then tell the software to solve the set of equations. This solution process is referred to as simulation, and the result is a time-history for each of the variables in the model. The time history for any particular variable can be displayed in either graphical or tabular form. Running "what if" simulations to test

certain policies on such a model can greatly aid in understanding how the system changes over time. System dynamics typically utilizes simulation to study the behaviour of systems and the impact of alternative policies.
We will be using the Vensim PLE simulation package[4] for CDEEP systems modeling, as it is easy to use and it contains all the tools that we need for simulating and analysing our system and most important factor is that it is available free of cost for educational purposes.

Chapter 3

Webcast Model

As discussed earlier, CDEEP System can be broadly classified into two sub-systems, the first one involved in live transmission via EDUSAT, and the second doing live streaming of IITB Courses over the Internet (Webcast) started in January, 2008. Since both these sub-systems have different set of viewers, and have different mode of transmission, we will consider both as independent of each other and will be modeling them as two different systems. There are currently 4 studios from where lecture videos are recorded and transmitted over Internet at bandwidth of 100kbps per connection. To access these videos students need only a PC and a minimum 100kbps Internet connection.

3.1 Webcast system : Initial Model

To model the webcast system, we followed iterative approach, first we identified key variables that determine/change the behaviour of the system, and their dependencies through which they affect each other, for example Total available bandwidth and Quality of Video are two such variables, and increasing the bandwidth would result in improvement in the quality of video because more bandwidth per connection can be provided.
Based on our understanding of the system, we identified important feedback loops in the system, as shown in the causal-loop diagram (fig. 3.1) and then we prepared equivalent Stock-flow diagram (fig. 3.2) to model the system, where we distinguished variables among stock, flow and connectors. We simulated and analysed the system using Vensim simulator. Initially we found following variables in system:

1. Total number of Students viewing the videos: This is the central variable in the system. This variable depends on student satisfaction, number of transmitted courses and quality of videos.

2. Student satisfaction: This parameter is highly dependent on the quality of video being transmitted and number of courses being transmitted. To quantify this variable we assumed that it varies between 0 and 1, where 1 being the best possible and 0 being the worst.

3. Total number of courses being transmitted in a particular semester: This variable is considered as constant (=20) initially.

4. Server Performance: As the number of simultaneous connections increase processing load on the server will also increase, and would result in server overloading and hence degra-

dation in quality of video. To quantify this variable we assumed that it varies between 0 and 1, where 1 being the best possible and 0 being the worst.

5. Quality of video being transmitted: This variable consists of many parameters that determine the quality of video, such as jitter, audio-video sync, delay etc. To quantify this variable we assumed that it varies between 0 and 1, where 1 being the best possible (when transmitted at 100kbps bandwidth) and 0 being the worst

6. Total available bandwidth: This is a constant and is taken as 8Mbps for our simulation.

7. Network bandwidth per connection: For each connection request to receive lecture videos 100 kbps network bandwidth is provided until it exhausts whole 8Mbps capacity. That means that up to 80(= 8000/100) connections will get 100kbps bandwidth, and after that with for each incoming request this 8Mbps bandwidth will be equally divided among the viewer. Hence more the viewers less will be the bandwidth per connection, which will result in poor quality of video at receiver end.

Using the above mentioned variables and their relations with one another we prepared a Casual Loop Diagram (CLD) (fig 3.2) and its corresponding Stock-flow Diagram(fig 3.3). As it is simply visible in CLD that there are only two feedback loops in the system and since both are negative feedback loops, as a result the system will show goal seeking or balancing kind of behaviour.

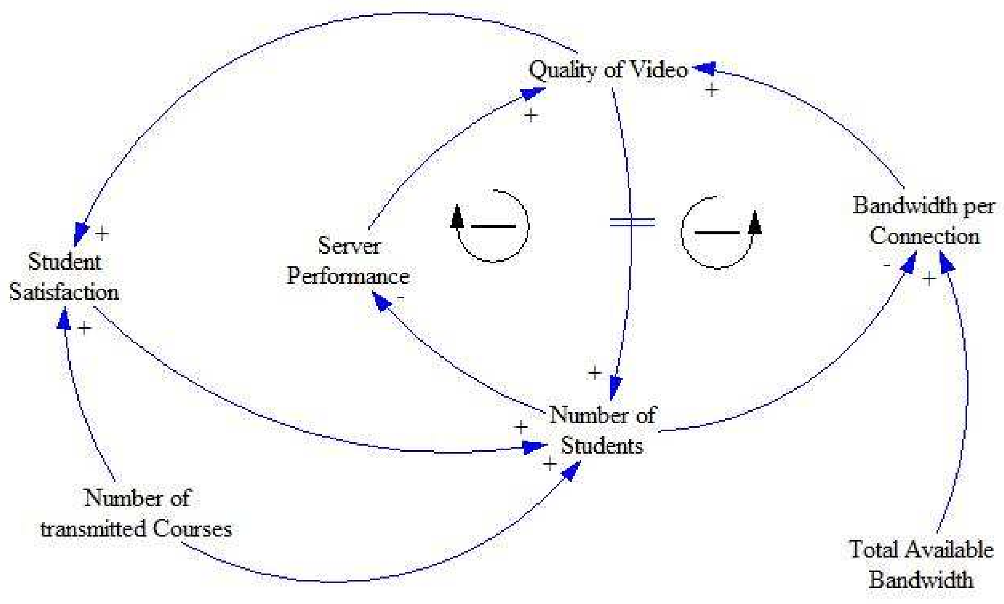

Figure 3.1: Causal Loop Diagram for Webcast system

We simulated this model in Vensim PLE simulator with initial values and equations shown in table 3.1.

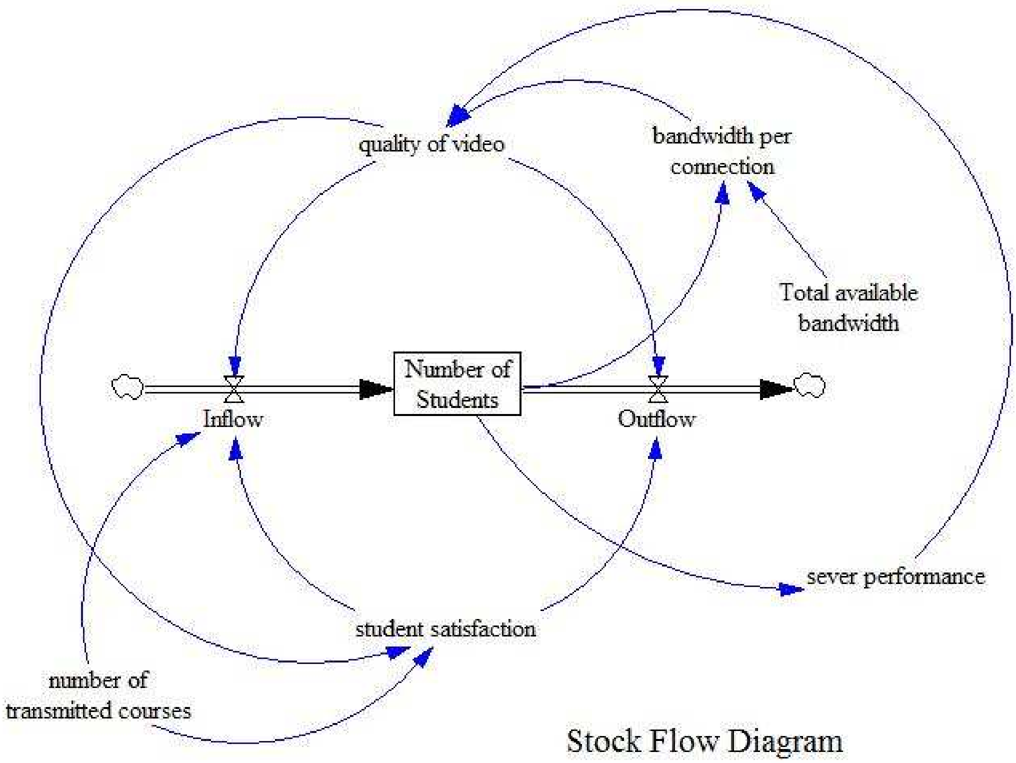

Figure 3.2: Stock-flow Diagram for Webcast system

Table 3.1: Variables, values and, equations

Variable Name	**Initial Value/Equation/Range**	**Unit**
# of Student	100, $Initial(\#\ of\ students) + \int_0^T (inflow - outflow)\,dt$	students
Inflow	$(Average\ student\ satisfaction$ $*Number\ of\ transmitted\ courses$ $*quality\ of\ video)$	students per month
Outflow	$INTEGER((1 - student\ satisfaction)$ $*(1 - quality\ of\ video") * 20)$	students per month
Total available bandwidth	8000	kbps
Quality of video	$(Server\ performance\ *$ $Bandwidth\ per\ connection/100)$, ranges between 0 and 1	Dmnl (dimensionless)
Average student satisfaction	$Quality\ of\ Video$, ranges between 0 and 1	Dmnl
Number of transmitted courses	20	course
Number of Studios	4	Dmnl (dimensionless)

Bandwidth per connection	$IF\ THEN\ ELSE(Total\ available\ bandwidth/$ $Number\ of\ Students > 100, 100,$ $Total\ available\ bandwidth/Number\ of\ Students)$	kbps/Student
Server Performance	$IF\ THEN\ ELSE(\#\ of\ students < 5000$ $1, (7000 - Number\ of\ Students)/2000)$, ranges between 0 and 1	Dmnl

3.1.1 Results and Discussion

We performed simulation runs for a time period of 4 years with varying values of different variables and obtained following results:

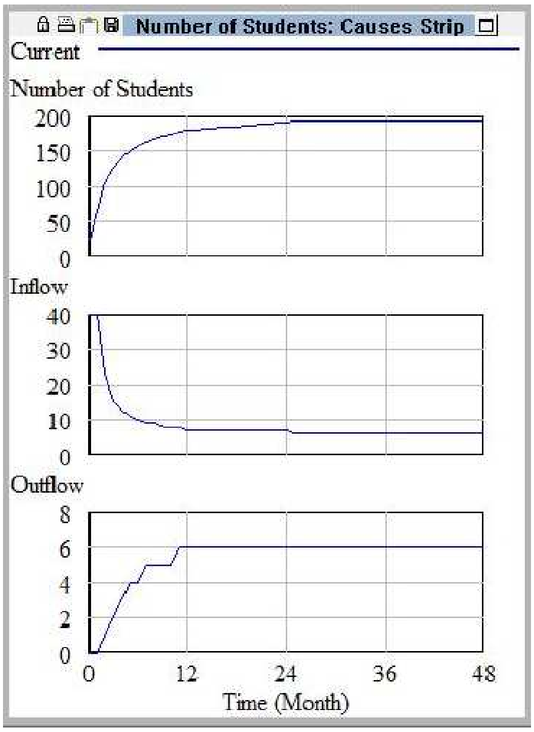

Figure 3.3: Change in Number of Students with time

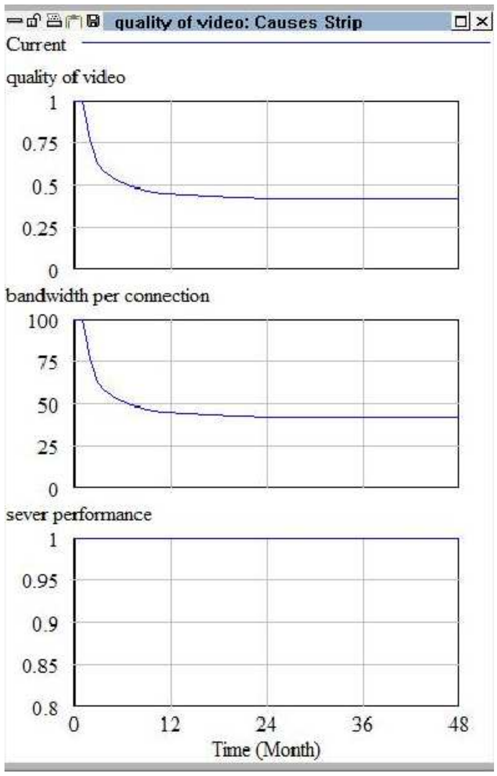

Figure 3.4: Quality of video with Bandwidth and server capacity

As it is visible in above graph that the variable *Number of Students* has become constant (=200 student) after 24 months, because the bandwidth per connections starts decreasing after 80 connections (8Mbps/100kbps=80), and hence decreasing the quality of video which will eventually decrease the student satisfaction, this results in increase in outflow and decrease in inflow, that means more students leave the CDEEP and later on there becomes an equilibrium between inflow and outflow, hence no change in total number of students. To keep increasing number of students network bandwidth needs to be increased, as it is the only bottleneck in the system. As shown in fig. 3.4 the sever performance is constant (=1) throughout the simulation period, because it is assumed that server can respond 5000 simultaneous requests before being overloaded, but this condition never arises because before reaching the limit of 5000 students, bandwidth becomes the bottleneck and hence students start leaving the courses.

If the total bandwidth is kept at infinite (let a very large value) even then also the number of students will reach only 2000 because the number of courses becomes bottleneck and keeps inflow constant. If we consider an ideal case when available bandwidth is increased to infinite (meaning very high, say 10 Gbps) and number of courses is also increased from 20 to 80, even then also the number of students remain constant after 6667 as shown in fig 3.5, because server starts overloading after 5000 students and hence quality of video starts decreasing, which results in an increase in out flow.

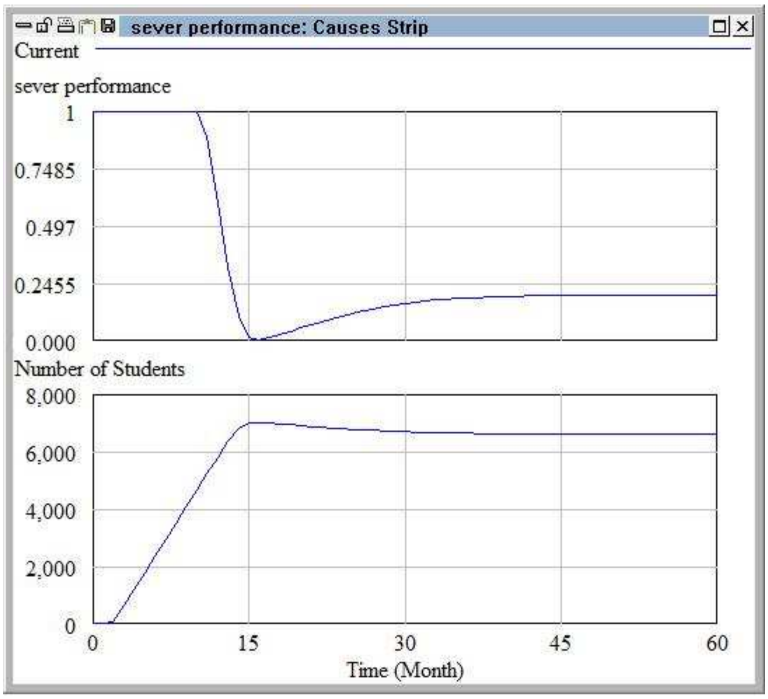

Figure 3.5: Ideal case when bandwidth is infinite and courses transmitted is 80

3.1.2 Limitations

Current model has certain limitations such as it does not have any variable related to marketing of CDEEP program as it will have large impact on the rate at which new students join the system. Moreover current model didnt introduce any variable about the grants from MHRD and also it considered the number of courses as a constant but in actual the number of transmitted courses has increased almost linearly in each semester based on the feedback from students. The number of transmitted course is also constrained be number of studios available for recording the lectures. It has been found that relevance of transmitted courses with other universities also plays an important role, but was not considered in initial model.

3.2 Modified Webcast Model

After studying the system more closely and analysing the initial model, we found some more variables that were not considered earlier, but they largely affect the behaviour of the system.

Following variables are included in the modified webcast model:

1. Grants form MHRD: Since CDEEP has received huge grants from MHRD after in April 2009, this would be a key factor in dynamic behaviour of the system, as we can utilize this money in various purposes. This event occurs only once. It is important to decide how to distribute this money and what would be impact of it. The money can be utilized in following manners:

   - Earlier as number of students increased the network bandwidth became bottleneck, After getting grants CDEEP can outsource the network bandwidth, now an external authority will be responsible to serve thousands of students simultaneously with 100kbps bandwidth for each student.

   - As the number of viewer increases demand for introducing more courses arrives. It is found that number of courses being transmitted is dependent on feedback of viewers. To transmit more courses simultaneously more studios would be needed for recording, number of studios can be increased from 4.

   - More money can be spent in marketing CDEEP programme, to increase the awareness about CDEEP among the potential students.

   - Currently CDEEP server is able to respond only 5000 requests simultaneously, after this it starts overloading. Money can be spent in upgrading the server.

2. Awareness about CDEEP videos: This is about, how more and more students are made aware of and encouraged to join CDEEP program. To quantify this variable we assumed that it varies between 0 and 1, where 1 being the best possible and 0 being the worst.

3. Number of studios: Currently there are 4 studios from where live courses are captured and transmitted. If numbers of studio are increased then more courses can be transmitted simultaneously. We assume that number of studios are increased from 4 to 6 after receiving the grants.

4. Feedback from the students: Students give feedback about their experience of CDEEP lectures, for example about the video quality or if more courses need to be transmitted. This helps in improving the student satisfaction. To quantify this variable we assumed that it varies between 0 and 1, where 1 being the best possible and 0 being the worst.

After including more variable we modified our previous Causal Loop Diagram (fig 3.6) and Stock Flow Diagram(fig 3.7).

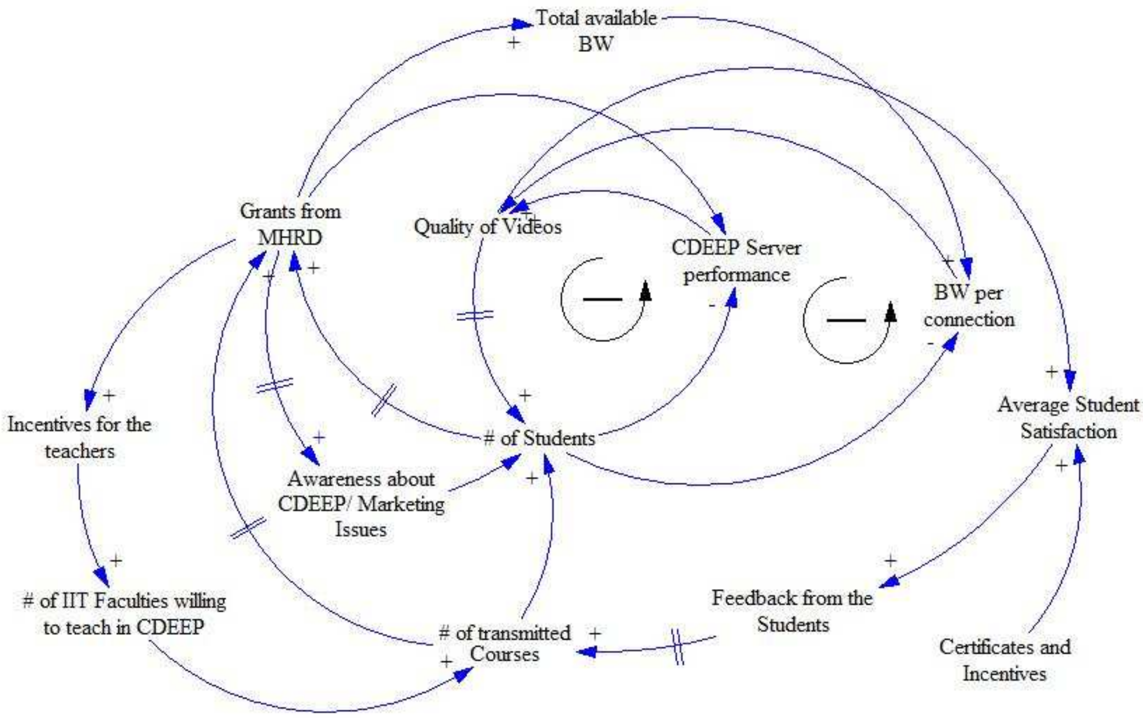

Figure 3.6: Causal Loop Diagram

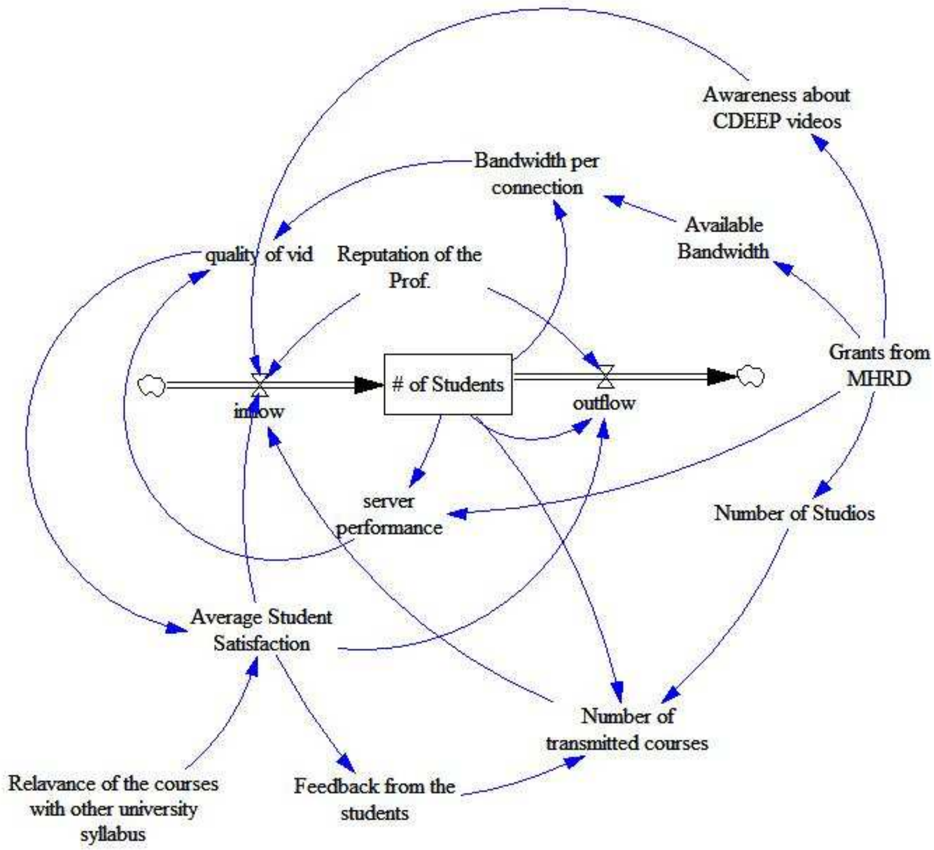

Figure 3.7: Stock Flow Diagram

Table 3.2 shows major variables in the system as well as their initial values and equations derived to show relation among different variables. These values were used for simulating various scenarios which are discussed in next section.

Table 3.2: Variables, values and, equations

Variable Name	*Initial Value/Equation*	**Unit**
# of Student	$Initial(\#\ of\ students) + \int_0^T (inflow - outflow)\, dt$	students
Inflow	$DELAY\_FIXED((\text{"}Reputation\ of\ the\ Prof.\text{"} *Average\ Student\ Satisfaction *Number\ of\ transmitted\ courses * 10 +Awareness\ about\ CDEEP\ videos * 4), 2, 20)$	students per month
Outflow	$INTEGER((1 - Average\ Student\ Satisfaction) *(1-\text{"}Reputation\ of\ the\ Prof.\text{"})*\#\ of\ Students)$	Students per month
Quality of videos	$Server\ performance * Bandwidth\ per\ connection/100$, ranges between 0 and 1	Dmnl (dimensionless)
Grants from MHRD	0, becomes $10\hat{7}$ after 24 months	Dmnl
Average student satisfaction	$Quality\ of\ vid * Relevance\ of\ the\ courses\ with\ other\ university\ syllabus$,ranges between 0 and 1	Dmnl
Number of transmitted courses	$IF\ THEN\ ELSE(Number\ of\ Studios > 5, INTEGER(20 + Feedback\ from\ the\ students* \text{"}\#\ of\ Students\text{"}/50), INTEGER(20 + Feedback\ from\ the\ students* \text{"}\#\ of\ Students\text{"}/35))$	course
Number of Studios	4, becomes 6 after 24 months	Dmnl (dimensionless)
Total available bandwidth	8000, becomes $10\hat{7}$ after 24 months	kbps
Bandwidth per connection	$Available\ Bandwidth/\#\ of\ Students$	kbps
Server Performance	$IF\ THEN\ ELSE(\#\ of\ students < 5000\ 1, (7000 - Number\ of\ Students)/2000)$	dmnl

3.2.1 Results and Discussion

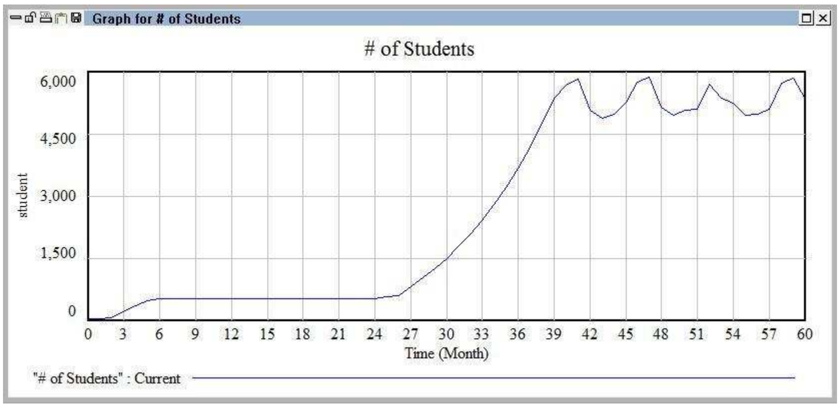

Figure 3.8: predicted number of students

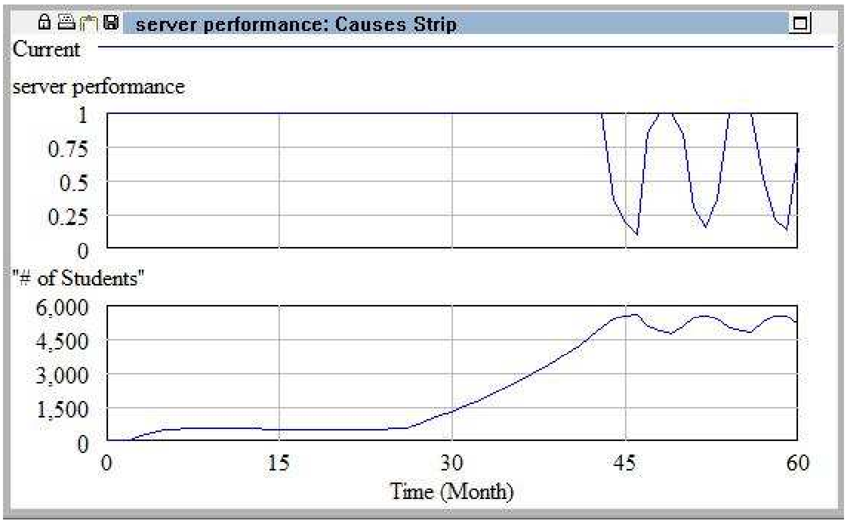

Figure 3.9: Change in *Server performance* with *number of students*

- Fig 3.8 shows predicted number of students for next 5 years, as it is visible number of students becomes constant(=600) after 1 semester. but since after April 2009 (4 semester after starting the webcast program) huge money is invested in increasing bandwidth and now the bandwidth becomes sufficient for all incoming students hence the quality of video increases rapidly and reaches almost 1(highest possible) and student satisfaction also increases the same way. As a result of this more and more students join CDEEP. After 45 months (4th semester after receiving grants) number of students stop increasing beyond 5700 because server starts overloading as shown in fig 3.9 and starts dropping the connections resulting in decrease in the quality of video. As a result of decrease in the quality of video students start leaving eventually, that decreases number of students and as a result again increases quality of video. This oscillation keep going on after that. To keep increasing the number of students, server performance should be improved after 22 months after increasing the bandwidth.
- After April 2009 if number of studios increases from 4 to 6, this will allow transmitting more courses simultaneously. Increase in the number of courses increases student satisfaction; it becomes another factor in increase in number of students.

3.2.2 Limitations

- It was not always possible to quantify the relation between variables, for example how will inflow change with Reputation of Professors, for such cases hit and try method was the only option. Many simulation runs needed to be performed with a different equation among the variables.
- Marketing issues could not be addressed because of lack of information and its effect on other events.
- Actual information about number of students watching the IITB courses is available. it makes it difficult to validate the model.
- It is not possible in Vensim to use nested IF ELSE THEN while defining the relation among the variables; hence we had to compromise from more realistic equations.

Chapter 4

EDUSAT Model

CDEEP transmits live courses through EDUSAT, ISRO's satellite. These courses are transmitted unencrypted and anyone who has access to student interactive terminals (SITs) of the Indian Space Research Organization (ISRO) can freely tune in to these lectures and also interact live with IIT Bombay faculty. Those colleges who have installed SITs are known as Remote Centres(RCs). Through the Student Interactive Terminals, two way live interaction is possible between students at the RCs and the instructor at IITB. The courses are mainly intended for engineering college students and working professionals, hence the targeted audience is totally different from those of live webcast.

4.1 Model Development

For modeling and analysing the functioning of EDUSAT system, we identified different variables which determine the behaviour of the system, by interacting and getting inputs from CDEEP staff members. The key variables in the EDUSAT system are:

- Number of Students: As discussed earlier, viewers of EDUSAT courses are college students sitting at Remote Centres, and hence is totally different from the student variable of webcast model. As shown in Causal-loop diagram in fig 4.1 total number of students attending EDUSAT courses varies with other variables which are total number of remote centres, number of transmitted courses, student satisfaction and quality of video received at remote centre.

- Remote Centre coordinator: Coordinators are responsible for ensuring proper functioning at Remote Centre. If something goes wrong with reception of lectures at remote centre, they are the first to contact CDEEP staff. The incentives offered to the RC coordinators and their motivation are partly responsible for the number of IITB courses that the students in the RC choose to participate in. They also provide quick feedback regarding students' interests in running courses.

- Relevance of course: In interviews with Remote Centre (RC) coordinators and students, we found that the alignment of the transmitted IIT Bombay courses to the university curriculum was an important factor in determining whether students would continue to participate in CDEEPs courses. In India all universities have their own syllabus, still most of the syllabus is common among them but syllabus of IITB courses is somewhat different from other universities, and students at remote centres sometimes find EDUSAT courses beyond their syllabus. Therefore including this variable in our model is justifiable, as it acts as an important factor in overall student satisfaction. While simulating, we quantified this variable as a constant parameter whose value could be fixed as a number between 0 and 1. In the Results section we discuss how the number of students depends on the relevance of the course.

- Number of transmitted courses: CDEEP has been transmitting UG as well as PG course for various engineering streams. Number of courses transmitted through EDUSAT is not same as webcast courses because out of four studios currently there is only one studio from where there is an up link for EDUSAT transmission. This variable also varies with the feedback from students, whether they want CDEEP to introduce new courses are not.

- Marketing efforts: This variable captures CDEEPs efforts at marketing its courses and to attract more and more institutes to become a remote centre. Through various means such as newsletters, and workshops more number of institutes, and students are made aware of CDEEP's program. This variable has been quantified from a 0 to 1 scale in our model.

- Support staff for equipment maintenance: They play an important role in proper functioning at remote centres. Many times it happens that even after getting complains about bed equipment conditions, immediate maintenance can not be done due to lack of sufficient support staffs.

Some variables are common between the webcast and EDUSAT model. Yet, the same variable is part of different feedback loops in the two models. One such example is:

- Quality of videos. In the Webcast model, the video quality of the course that a student participates in mainly depends on the availability of sufficient bandwidth, which changes with number of simultaneous connections. While EDUSAT have a dedicated 1 Mbps up link and 500 kbps down link for transmission. In the EDUSAT model, the video quality is affected by the condition of the Equipment at the RC. This variable has again been quantified on a scale of 0 to 1, and it has been held at a constant value of 0.5 which represents the average condition of equipment at the RCs.

Using these variables and their interaction with one-another we have prepared the *Causal Loop diagram* for the model in fig. 4.1. This diagram shows how different feedback loops in the systems that are responsible for its non-linear behaviour. Using this diagram we prepared a corresponding *Stock-flow diagram* (shown in fig. 4.2) in Vensim simulator.

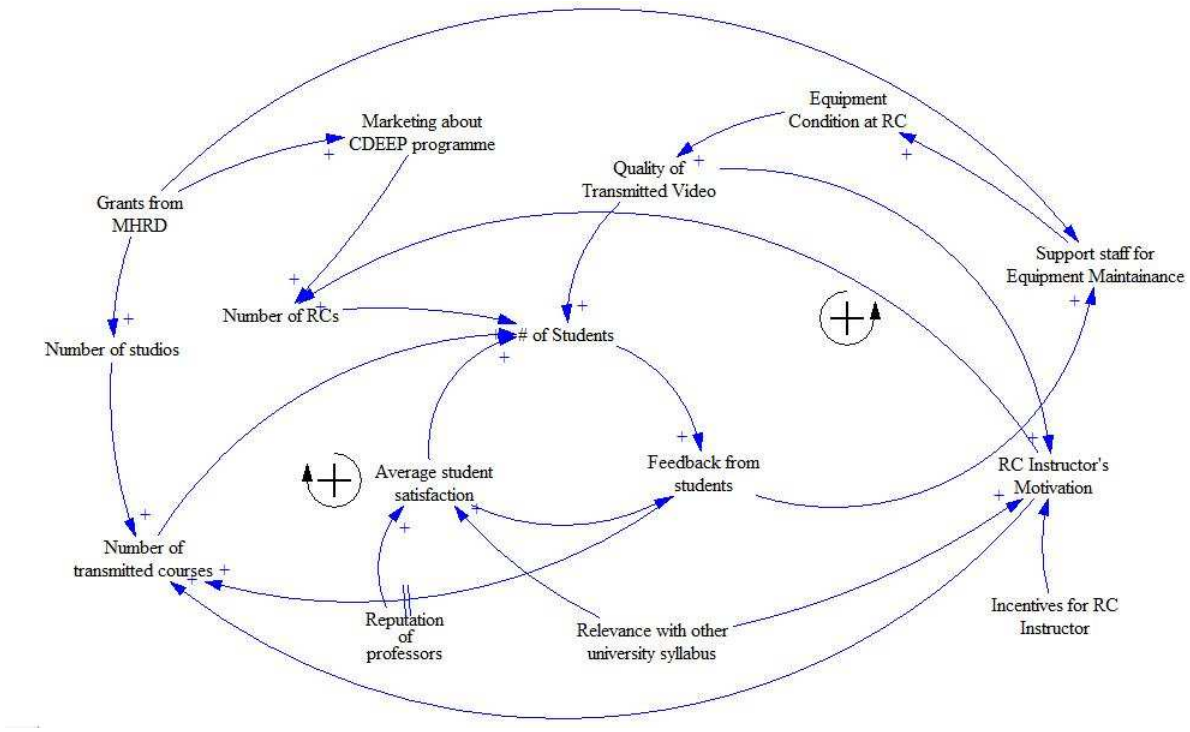

Figure 4.1: Causal Loop Diagram

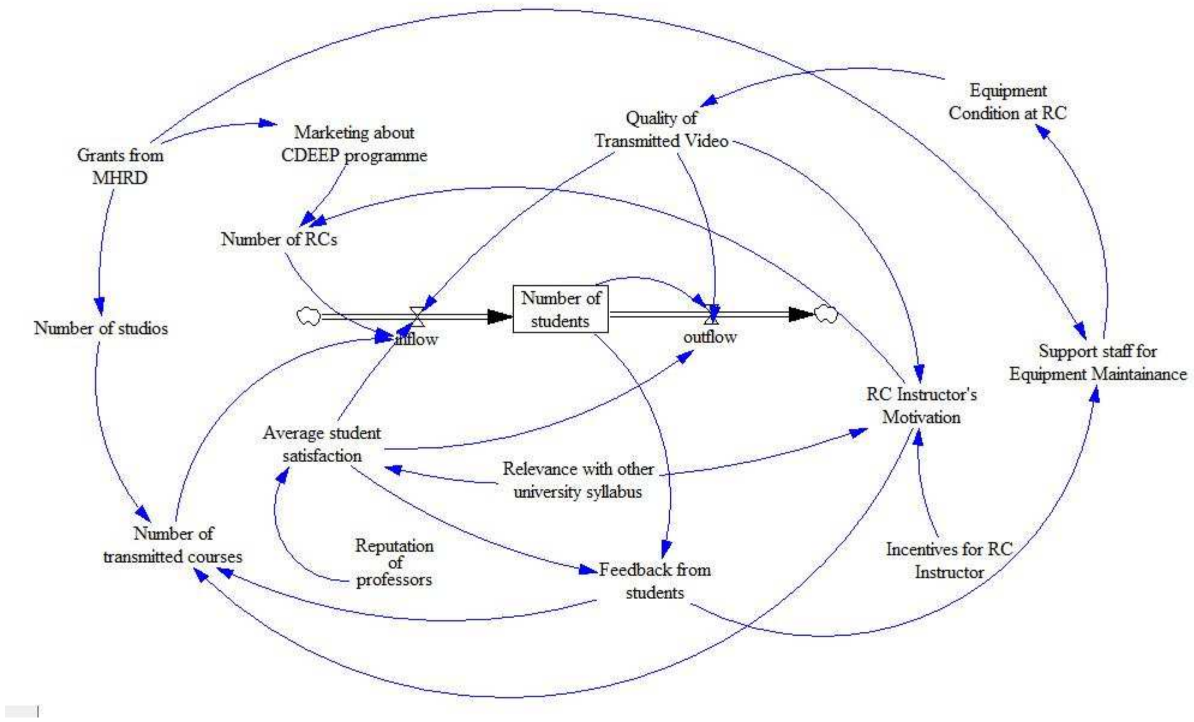

Figure 4.2: Stock Flow Diagram

For simulation of the above model, values of different variables were gathered from the CDEEP staff. We also derived some equations which represent the relation among the variables. Table 4.1 shows different variables, their corresponding initial values or the equation to determine the variable and the units of all the variables in model.

Table 4.1: Variables, values and, equations for initial model

Variable Name	Initial Value/Equation	Unit
# of Student	$Initial(\#\ of\ students) + \int_0^T (inflow - outflow)\, dt$	students
Inflow	$DELAY\_FIXED((\text{"}Reputation\ of\ the\ Prof.\text{"}$ $*Average\ Student\ Satisfaction$ $*Number\ of\ transmitted\ courses * 10$ $+Awareness\ about\ CDEEP\ videos * 4), 2, 20)$	students per month
Outflow	$INTEGER((1 - Average\ Student\ Satisfaction)$ $*(1-\text{"}Reputation\ of\ the\ Prof.\text{"})*\#\ of\ Students)$	Students per month
Relevance with other univ. syllabus	0.6	dmnl
Quality of videos	$Equipment\ condition\ at\ RC$	Dmnl (dimensionless)
Grants from MHRD	0, becomes $10\hat{7}$ after 24 months	Dmnl
Average student satisfaction	$Quality\ of\ vid * Relevance\ of\ the\ courses$ $with\ other\ university\ syllabus$	Dmnl
Number of transmitted courses	$IF\ THEN\ ELSE(Number\ of\ Studios > 5,$ $INTEGER(20 + Feedback\ from\ the\ students*$ $\text{"}\#\ of\ Students\text{"}/50),$ $INTEGER(20 + Feedback\ from\ the\ students*$ $\text{"}\#\ of\ Students\text{"}/35))$	course
Number of Studios	1	Dmnl (dimensionless)

4.2 Results and Discussion

We performed simulation runs of EDUSAT model for different scenarios, and analysed the results. We considered following scenarios:

1. Behaviour of existing system and effect of incoming grants: In figure 4.3 we have shown the future behaviour of the system as well as the the effect of incoming grants. If the CDEEP system runs in its regular annual budget and no extra grants enter the system, then the maximum number of students is about 600 even after a period of 5 years, which is very less than what is the goal of CDEEP. Since CDEEP has received huge one-time grants from MHRD, If we include this grant entering the system at month 24, then the number of students increases to 2400 after 5 years. In the simulation the grants have been used to increase the number of studios from 1 to 4 and also marketing expenses have been increased to 0.7 from 0.3.

2. Marketing vs Number of courses: Instead of concentrating on only marketing about CDEEP, we need to concentrate on increasing the number of courses transmitted per semester as well. According to the simulation results if we are putting efforts in marketing only, we can increase the number of students up to 315 after 18 months. And if we increase the number of courses 45 without concentrating on marketing then we would fetch at most

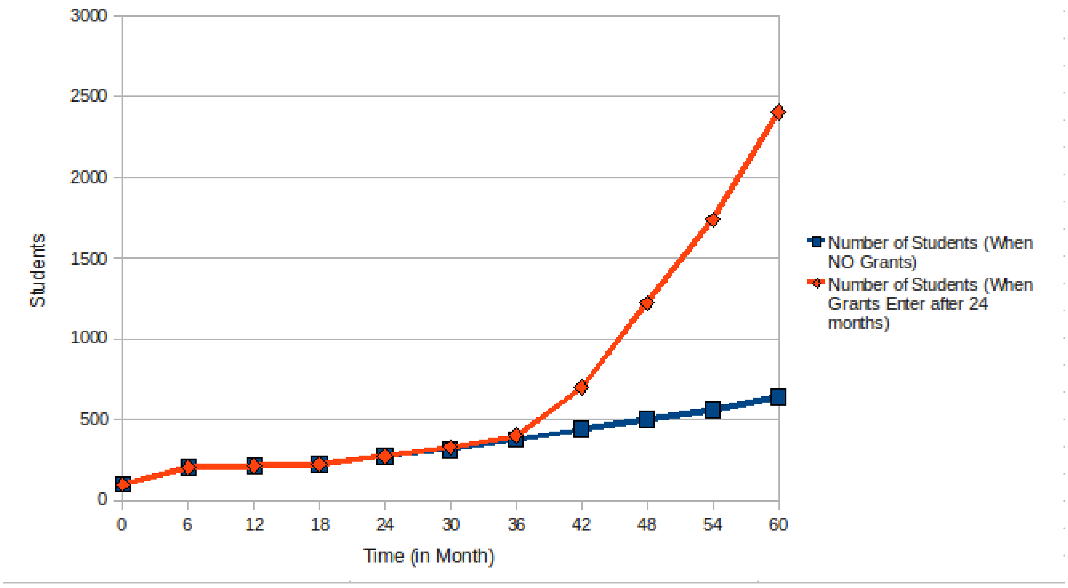

Figure 4.3: Effect of Incoming Grants

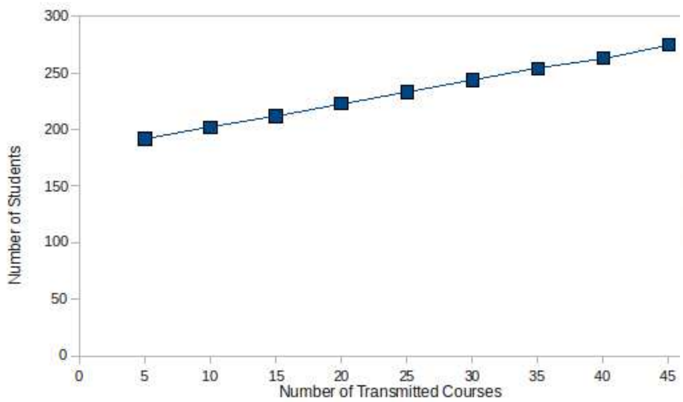

Figure 4.4: increase in number of students with number of transmitted courses

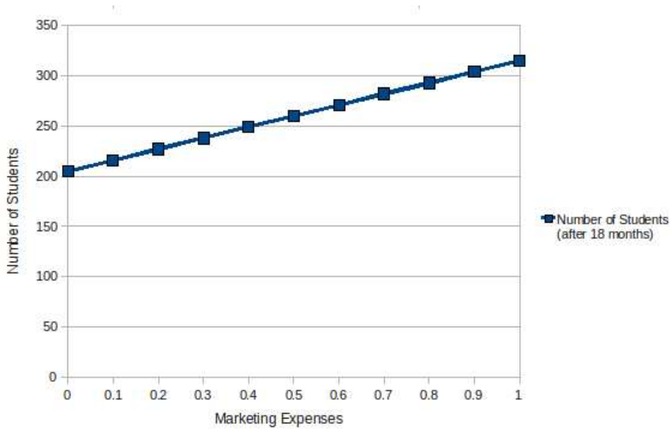

Figure 4.5: increase in number of students with marketing expenses

260 to 270 students after 18 months, but If we increment the number of courses to 20 and put some efforts in marketing too (0.7 out of 1) we get significant improvement in number of students and it reaches to 373 after 18 months.

3. Relevance of the courses with other universities: As mentioned in section 4.1, the alignment of the syllabus of IIT Bombays transmitted courses to the curriculum followed by the students in the RCs is of great significance. In Figure 4.6, we see the how the course relevance affects the number of students. If a course has low relevance, say 0.2 on a scale of 0 to 1, then the number of students in fact decreases from 6 to 12 to 18 months. while If a course has high relevance, say 0.8, then the number of students increases. Further, the increase or decrease of students occurs at a faster rate at the 18 months than at 6 months. This shows that the impact of course relevance becomes even stronger as more time goes by.

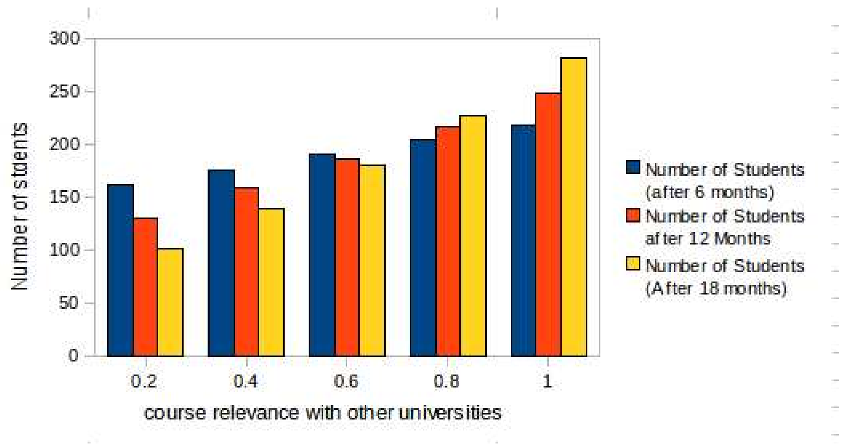

Figure 4.6: Effect of relevance of courses

A poster titled **"Using System Dynamics to Model and Analyse a Distance Education Program"**, covering our model and the results obtained through the simulations, has been accepted in *International Conference on Information and Communication Technologies and Development 2010.*

4.3 Recommendations

The results from the system dynamics simulation of EDUSAT model along with results from Webcast model gave us valuable insights into making policy decisions in our program. At first significant improvement in network bandwidth is needed, as it is the first resource which becomes bottleneck(fig 3.4), because of this quality of videos degrades and as a result number of students stop increasing after a certain limit. Investment made in purchasing more bandwidth will result in very rapid increase in number of students (fig 3.8). Another recommendation that emerges from our study is that sufficient attention should be paid for obtaining high quality servers but it is needed only few months after bandwidth is increased, because server performance would become a bottleneck later on (fig 3.9). In addition attention needs to be paid on publicizing CDEEP programs and encouraging student to join CDEEP (fig 4.5).

We studied the role injection of grants into the system. Even though this was a one-time event, its effect is significant. Even if CDEEP administrators seek extra funding for the system only once in while, it will help in improving the outreach of its courses, provided the funds are distributed in an optimal manner to various parts of the system. The system dynamics modeling tool has proved to be very useful in this case as a predictive mechanism. The distance education programs administrators could use the simulation results to determine what parts of the program should be allocated what percentage of funds, and at which times. If CDEEP wants to achieve its goal of reaching out to a large number of students, it is essential that the courses transmitted by CDEEP are well aligned with the specific curricula of students who are viewing the courses (fig 4.6).

Chapter 5

System Dynamics Modeling Tools

Having performed the modeling and simulations of CDEEP system model, we took studying system dynamics modeling tools as our next task, and see if we could contribute for the development of system dynamics simulators. In our study we found that the System Dynamics modeling methodology is a 50 year old technique but still there is no standardization of modeling framework. The current software tools are proprietary applications. There is generally very limited collaboration among them. Opensource solutions available at Sourceforge[5] include Sphinx, OpenSim, SystemDynamics and SystemML. These projects have failed to be completed by developers or utilized by researchers and consultants because their underlying data structures (their information models) were inadequately defined. These solutions all implement incompatible or incomplete information models except for elements of a few of the most basic model components. Hence no truly successful open source System Dynamics model builder or simulation applications is currently available.

We explored *SystemDynamics*[6], an open source system dynamics modeling tool available at Sourceforge, aiming to make contribution to the open source community via adding some new features or fix any bug in software, but there was no proper documentation of the code available, and the code was too huge(around 50K lines of code) to be understood without documentation. Hence we dropped the idea modifying the software, but while exploring the code we identified major components of a system dynamics simulation model. We also referred the System Dynamics Information Model project[7] that had taken an initiative to prepare a modern framework about system dynamics models, and prepared a higher level flowchart (figure 5.1) of system dynamics information model framework and shown various model objects (such as stocks and flows), the scope of their relationships, and the necessary operations performed during model building and simulation.

In figure 5.1, the following elements are introduced:

- Component: a model component is a basic system dynamics function block such as a stock or flow.
- Fragment: a fragment is a collection of model components i. e. it is a subset of the model
- Primary Model Layer: the primary model layer represents the fundamental model, this fundamental model can be the entire model, or it may be core part of the model to which other parts of the model may refer for internal variable values
- Abstraction Layer : an abstraction layer is a separate layer of the model that facilitates model partitioning, and simulation partitioning; an abstraction layer refers to the primary model layer for interval variable values

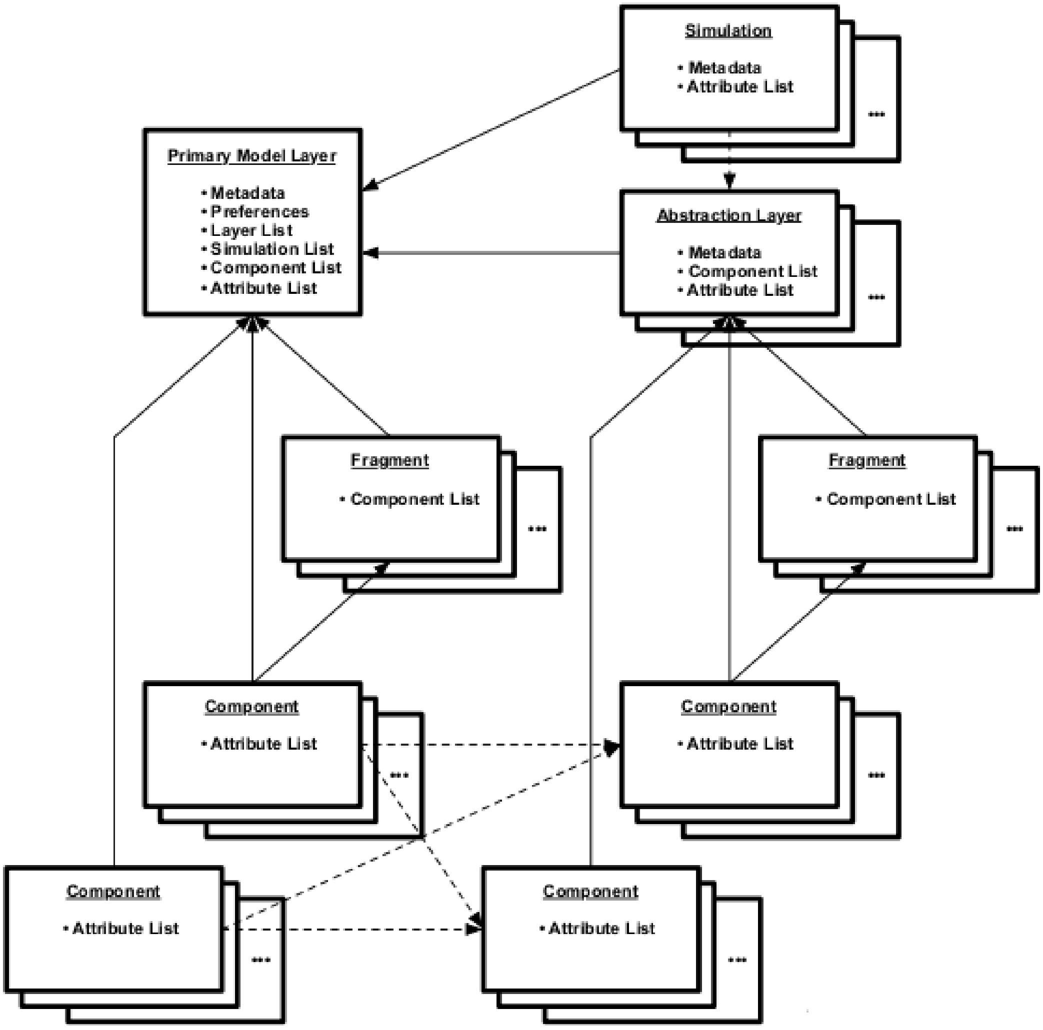

Figure 5.1: System Dynamics Information Model

- Simulation : a simulation of a system dynamics model is the sum total of calculations specified by the model over a sequence of time intervals; a simulation also includes a collection of attributes that establish boundary conditions, initial states, output options and other simulation options

- Metadata : metadata is a collection of information that provides details such as a name, version, model owner, creation or revision date, an abstract and other useful information

Here a solid line and arrow shows containment, for example the primary model layer contains components. A dashed line and arrow identifies a less significant relationship, for example an abstraction layer model component makes use of a primary model layer components attributes such as its value.

The model has the following basic data structures:

- METADATA: It is the minimum metadata to define model ownership, version control, security, and searchability

- PREFERENCES: These are a set of settings that affects appearance, abstraction and other model-specific qualities such as symbol size, symbol spacing
- COMPONENT LIST: The unique set of registered names of model components and fragments contained in the model primary layer for example component name, type, shape, location etc.
- LAYER LIST: It defines a list of abstraction layers in the model
- SIMULATION LIST: It contains the list of named simulation scenarios.

Here a system dynamics model has been described in the form of information model with its data structures. An open source information model specification is the first step for any further specification work or application development. Follow-on open source projects may include an open source metadata specification that is compatible with another open source projects to enable model warehousing. The primary benefit of the specification will be improved collaboration between researchers who currently use various proprietary tools for their work. A formal specification of the methodology will also improve the communication of ideas, and the proprietary tool vendors may be convinced to include open source model import / export methods into their products.

Chapter 6

Conclusion and Future Work

In this project we modeled CDEEP program from a systems behaviour perspective. By analyzing the structure of CDEEP using system dynamics simulations, we obtained insights into performance of the program. Many of these results could not have been obtained by simply looking at isolated events and their consequences, due to the various interacting parts within the system. Results from the simulations gave us understanding about possible factors to improve the behaviour of the system. We might not have considered some of these factors in CDEEP future plans without this study.

It would be worthwhile for institutions that are starting a distance education program to analyze their plan using a systems dynamics model. Early warnings of the possible pitfalls in the plan could emerge from the results of the simulations. New aspects that had not been anticipated could become visible. Distance education programs that are already functional would also benefit from running a system dynamics simulation of their program. Due to the complex nature of systems behaviour, results of a system dynamics simulation are often not obvious. These results prove to be useful for existing problems, making policy changes and strategic decisions. Program administrators could get an insight into questions such as: what would happen if a certain policy were changed, or how would we distribute existing resources into different parts of the system. System dynamics offers us a theoretical tool to analyze such a structure, and gain an understanding into the performance of the system.

As continuation of this work, results and recommendations made could be validated by implementing them over the actual CDEEP system. The Webcast and EDUSAT models have been prepared after getting inputs from CDEEP staffs, past data and the feedback gathered from students, and hence the results are as good as the model itself Since we could not implement our policy recommendations on the CDEEP, and see the validity of our claims. This task can be done in the subsequent work.
The current software tools for system dynamics modeling are proprietary applications. Open-source projects for such tools have failed to be completed by developers or utilized by researchers and consultants because their underlying information model were inadequately defined. No truly successful open source System Dynamics model builder or simulation tools are currently available. This task can be taken in hand to improve the tools, and to expand the application of this modeling technique to a broader community of users.

Bibliography

[1] http://www.cdeep.iitb.ac.in/.

[2] http://www.wikipedia.com/Sytem_Dynamics.

[3] http://www.public.asu.edu/~kirkwood/sysdyn/SDIntro/SDIntro.htm.

[4] http://www.vensim.com.

[5] http://www.sourceforge.net/.

[6] http://www.sourceforge.net/projects/system-dynamics.

[7] http://sourceforge.net/projects/sdinfomodel.

[8] *System Dynamics Modelling, A Practical Approach.* Chapman & Hall, 1996.

[9] McKansey Global Institute. Emerging global labour market. 2005.

[10] Deepak B. Phatak Kannan M. Moudgalya and R. K. Shevgaonkar. Engineering education for everyone: A distance education experiment at iit bombay. *Frontiers in Education*, 2008.