Introduction to System Dynamics Modeling
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Lecture – 26
Course Wrap-up

So, today the title says we will have the summary discussions on the course and a kind of Course Wrap Up presentation. But still there is some activity for Thursday, I will come to that end of the lecture, it is not yeah. So, let us quickly or we can take a time we have an hour to look the various aspects of the systems course that we have done and then we can take a look at what we were what I thought have a try to convey and see whether you have also have the same thinking.

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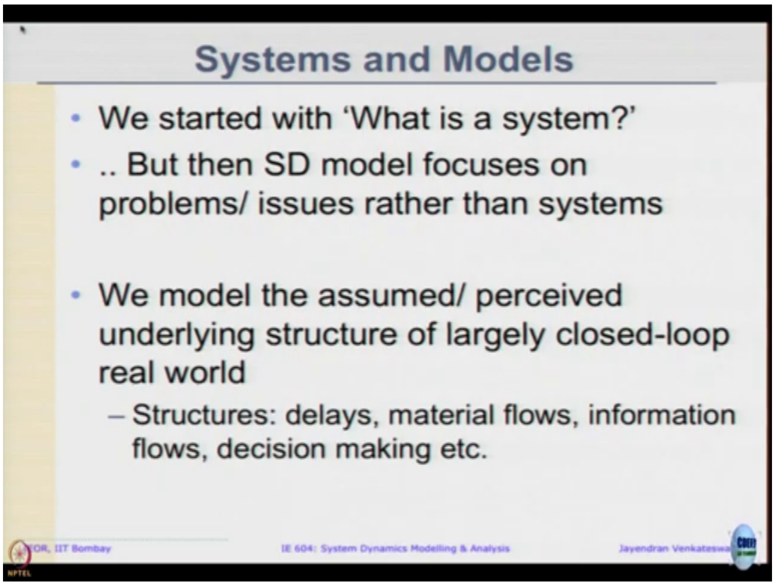

We started with systems that we when our first question asked as a what is the system and then we talked about that it is you know, system something made up of many interacting components or parts is what we defined. But then immediately almost immediately we abandoned the system because, even though course title course system dynamics, you only model the problems or issues you can never model the system. That is the first kind of ironical that we did not really (Refer Slide Time: 01:32) system. But it is the system view of things and started focusing on a problems and issues.

So, what we overall what we want to model? We want to model the assumed or perceived underlying structure of largely closed world closed loop real world problems. What we mean is we want to find out endogenous explanations for whatever phenomenon we are observing or whatever thing is happening. We want to observe we want to incorporate that as part of our model, sometimes we need to make assumptions and we need to bring out this underlying structures outside.

It may not be readily apparent, so we underwent discussions and then making some assumptions creating table functions to actually elicit this model and kind of build a closed loop model of the entire scenario. We ended up using various structures like delays, metal flows information, flow decision making etcetera were all incorporated.

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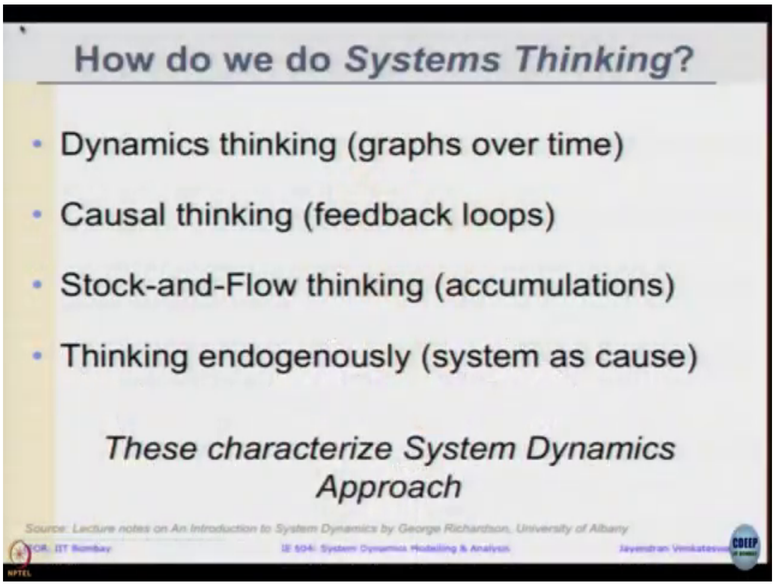

How did we do system sinking? These are the some of the components that we were went through shallow dynamic thinking, that is graphs over time or behavior over time graphs we are constructed. And we have been and looking at it for the entire semester, then we started to think about feedback loops using causal loops diagrams and they notion of causation variably affecting variable b then what manner is discussed. Then we try to incorporated in a stock and flow thinking where accumulations are clearly model and then we move to simulation modeling of it and thinking endogenously system is the cause like.

What is within the system that is driving the behavior that is explanation we were trying to see; then all the models that we are try to build. Again summary we need and remember these all characterize the system dynamics approach that we have done.

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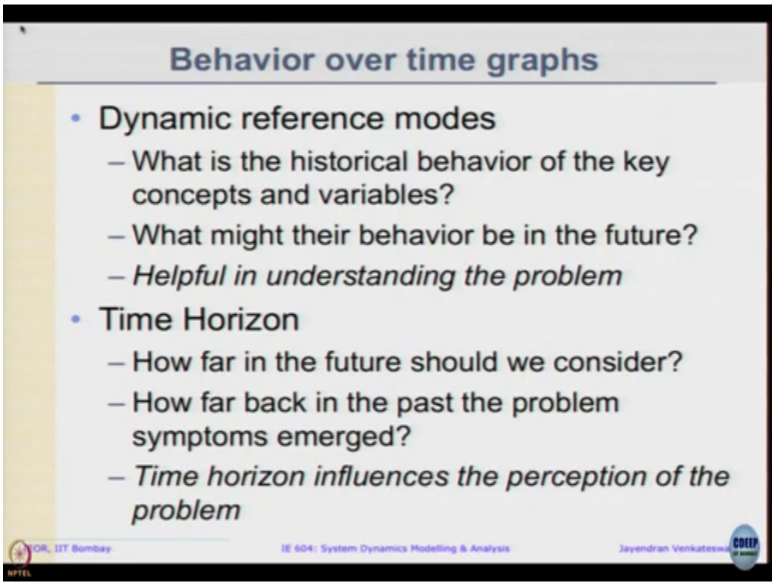

So, this behavior or time graphs, again what does it mean? So, behavior or time graphs what you want to represent is there also known as a Dynamic Reference Modes.

So, when you are actually building a new model, we might a want to look at what is the behavior of the system over time in the past, it was a historical behavior. And then what might be the behavior in future also this is helpful and understanding the problem. But of course, as soon as we start talking about the historical behavior, we need to also worry about a time horizon like how far in back we really want to consider and when need the problems come out it and then that will give an idea of what we want even actually model.

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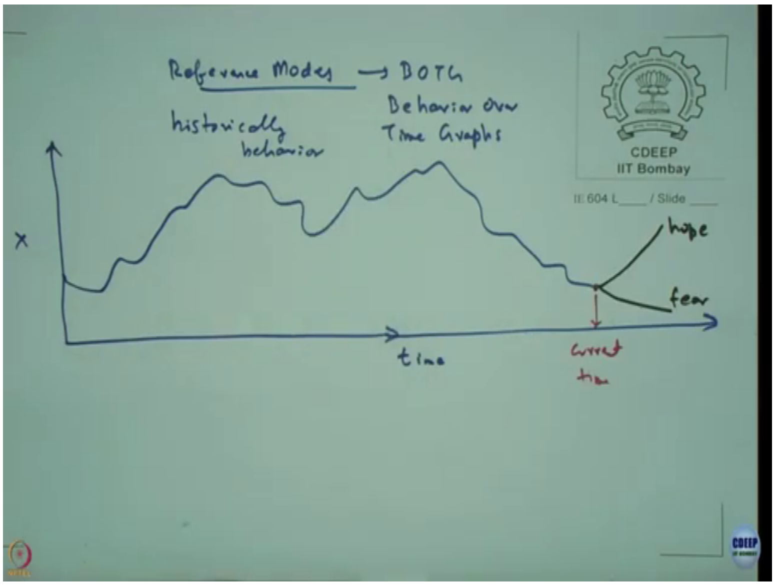

So, for the first part what you call as the reference modes, reference modes are nothing but behavior over time graphs BOTG means Behavior Over Time Graphs. This is a kind of a explanation. If you want to say model real system or you want to look for something where you feel may be a systems approach will be useful, may not be necessarily you are using system dynamics modeling. But you want to do a systems approach in the sense that we want to look for endogenous explanation within the system we want to how the variables are being interlink.

So, then one of the first think we might want to look at this reference modes and reference modes again x axis is always time. This is some variable of interest some variable X of intersect where looking at and if this behavior is a linear straight line not interesting. If it is linearly increasing again not much interesting linearly decreasing not much interesting even if it exhibits an exponential growth that also we know it can be modeled as a very kind of simple system. If it is exponential d k the underlying structure is quite straight forward that we want to model. So, it may not or if it is you know goal seeking model does not require too much effort we can actually make the things explicit.

What you will make interesting is suppose we have graphs like that, where we can see pronounced non-linear effects non-linear behavior that is happening something is causing it to increase, something is causing short term fluctuations, something is causing long term fluctuations in the model something is increasing and decreasing.

So, whenever there is at least some increase or decrease or shift increase and decrease denote there is a shift in the feedback systems. That means, at least is two feedback systems it is operating. So, one is driving growth the other is diminishing growth and there is a shift in those feedback system is happening endogenously. What it is now becomes an interesting question to try and uncover right.

So, one of the first thing we want to do is look at some of the key behaviors and see what kind of patterns that we actually seeing. So, these are called as reference modes, because mainly they are look at the historical behavior. So, suppose we are here this is the current time, typically we would end up drawing couple of patterns in it like what we call as a hope or fear. These two trajectories represent what you hope system will behave in future and what you fear the system may actually end up doing in the future.

It can be other way around you might want to hope the system goes down and fear could be the it versions, it is just an assumption here that larger is better. So, hope is higher versus that just implicit assumption. But it can be other way also increasing can be fear and decreasing can also be a hope that system actually sub (Refer Slide Time: 07:57) ends. You know like if it is your whatever to somebody sick and this is their fever profile you might wanted to your hope is system is upside and say people become better way. So, it can be that could also.

So, but this kind of we want to see whether if you are able to build a model which reasonably predicts, reasonably replicates this behavior, then in future we may see what happens in future and have more trust in the model. So, that is why the reference mode becomes important to see what we want to replicate or behavior or time graphs should be BOTG. So, one exercise or one thought process for many of field you know various projects in various fields, you might want to look at a some other data that is actually changing over time and see what kind of dynamics are there. From most often system will look highly non-linear and with short term fluctuations with and long term fluctuations ok. I have few examples about this time horizon.

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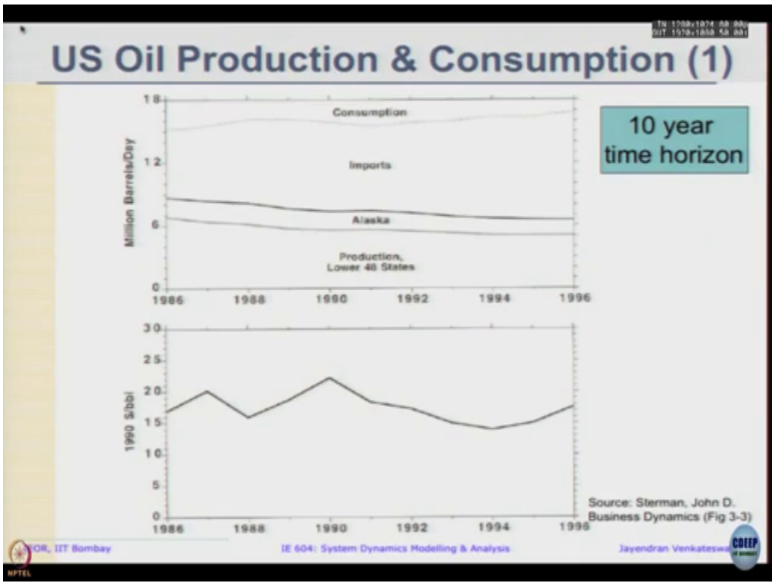

So, time horizon effects how much we want to see for example, given Sterman's book, this is looked at 10 year time horizon of the oil production and consumption. The consumption is a kind of flat the inputs production in lower states or this line here and in Alaska fills the gap. So, the rest of the consumption is a handle through inputs, it is fairly stable with the slight decline and production and slight increase in consumption is flat. So, production seems input seems to be a increasing steadily. This is a dollar price per barrel it seems fairly flat over 10 year horizon.

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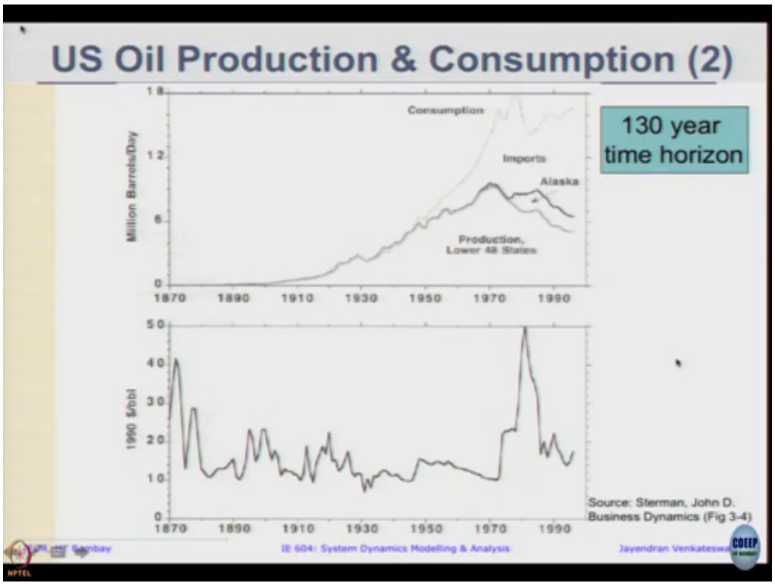

However if we increase the time horizon to since kind of oil was discovered, you can find a nice rapid exponential growth within the model and say a peak seems to be the first oil crises hits 1970 and since then it has been kind of falling down over time.

So, this suddenly changes a perception of what is the model that we want to have. The previous one may sound like we have in a preserves you can keep going, but here there is a kind of rapid decline that is being nicely captured in this kind of a time horizon and price (Refer Slide Time: 10:314) fluctuations especially recently.

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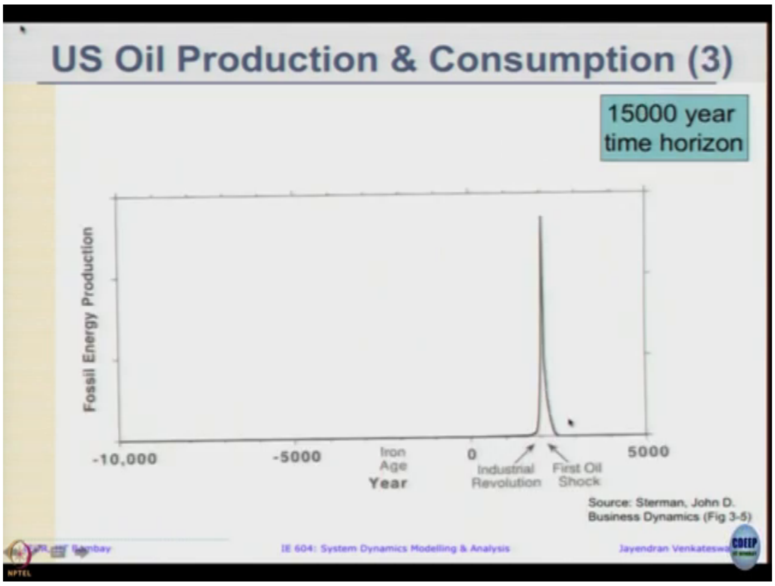

Because two large a spike probably just simple pulse change with the time scale is really high some 5000 years in future, then because just pulse in pulse change that has happened without effecting anything else.

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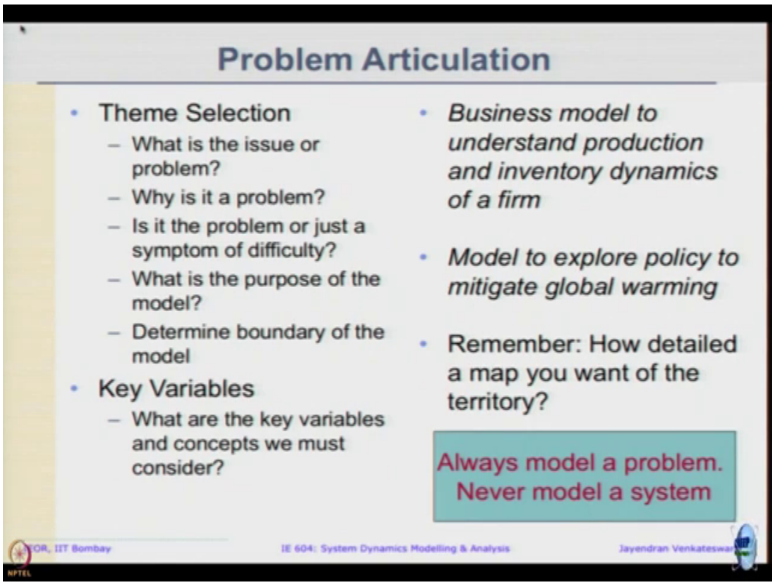

So, it is burden to select the time horizon. Then we through various examples we try to do this part of articulating what the problem we wanted to solve, ideas to what is the issue or problem why is it a problem is it just a symptom or difficulty what is the purpose of the model that we want to do. Then we need a determine some boundaries for the model like we told some variables endogenous some are exogenous let us assume that demand is exogenous for example.

So, those are the assumptions reasonable are not be (Refer Slide Time: 11:30), appropriately we drew the boundaries for the model. Can I consider key variables and concepts and used it in your model. Examples include business model to understand production inventory dynamics of a firm, we did that model to explore policy to mitigate global warming it did not work on that. But these are some examples where the scale is completely different, when you look at the business model you looking at one company's model their perspective, their policies, their management structure, their management policies etcetera built in and how they interact with the consumers is the model.

But when we start talking about policy mitigate global warming, suddenly you are in looking at thinking of a model which talks about the entire world and how various industries. Does not matter what type of industries or activities happens how it contributes to this global warming is what we are how interested in. So, the scale the dynamics the type of variables all are going to refer. In how detail a map you want of the territory effects the size of the model that we want, we want the entire world or you want to look at a small isolated region is it one business or is it multiple businesses, one cities multiple cities what is that we want is a is a plus from. We model with the systems view of things, but we never lost track of the we do not want lose track of the problem that we are trying to see. Like a when a the approach taken to teach it could be that there are descriptions given.

So, it felt like the problem is already defined or was not really apparent. What we wanted to see is there are some fluctuations in say housing dynamics that happened, we are seeing some population increases and decreases we are trying to look at model trying to explain that. So, we want to revolve around it. So we have some variables and how does this variable affect the next one and how does that effect the second one etcetera we keep going, so that is approach we want to take.

To why never a system is because, then whenever we start then we will end up modeling the entire world, then only model that will ever work is the entire world model that also may be limited then we want to model for the entire universe or whatever. So, it is too it will become too big too quickly, like if you want to model the say agricultural pricing like right. Now potato is a big issue right in some districts in Uttar Pradesh I do not know if you are following the news earlier it was sugar cane the last year it was Toor Dal, here there is lot of inventory of Toor Dals.

So, it keeps happening in cycles, so those are actually called as production commodity cycles. This been well studied and how it keep changing because it just divide by the supply and the demand. And because of the lead time things get to accumulate and things like that, which affects in a longer terms people who can short term solution because election comes more often than people are going to see the cycles. So, people are interested in short term fixes which anyway that is the policy part. But then if you want to model that then we are going to focus on let us look at what is the dynamics, so potato inventory that is happening.

So, and we do not want to model every agricultural product it entire northern belt it looking at let us model the potato the inventory of potatos. So, the pricing of potatos and their money the farmers get within a reason say in Uttar Pradesh. So, that is what you mean by focus on a problem. So, the entire system may be slightly bigger then what we want ok.

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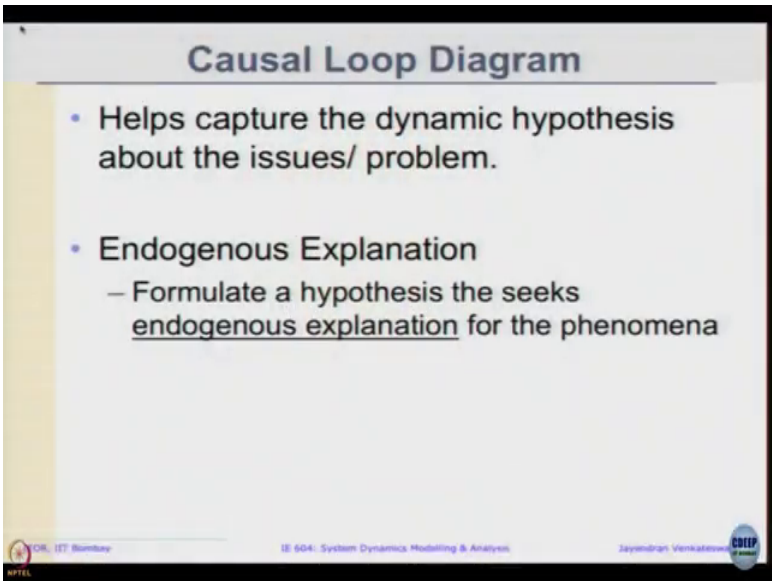

So, do all these problem articulation we actually used causal loop diagram. What the causal loop diagram actually captured is what is called as the dynamic hypothesis. In statistics and other fields you must have studied about den hypothesis and testing of hypothesis. Here the probably of first time we are actually defining something called dynamic hypothesis, because I say actual behavior overtime that we are capturing and the causal loop diagram does not capture system in static capture system as it changes over time.

And we want to define the causal loop and see this diagram we expected to you know cause the underlying dynamics that we are actually seen. So, that is hypothesis that we want to then validate using simulation model and very phase in simulation models and always you try to seek for this endogenous explanation of the phenomenon.

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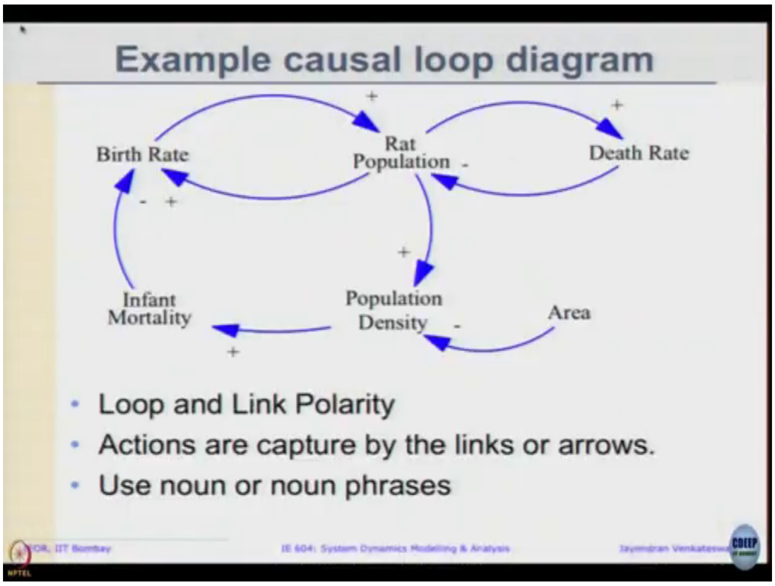

Ah we drew many such causal loop diagrams, as shown here we identified variables used arrows to say how say birth rate effects rat population, plus all causal links had polarities plus sign indicates as birth rate increases population increases or negative sign indicates that birth rate death rate increases, the population actually comes down the impact is in opposite direction.

If in a loop all the links are positive then we have positive feedback systems, if odd number of links are negative then it becomes a negative feedback system. I shown here birth rate rat population density increases population is increase increases infant mortality infant mortality increases birth rate, effective birth rate kind of decreases that becomes a negative feedback system.

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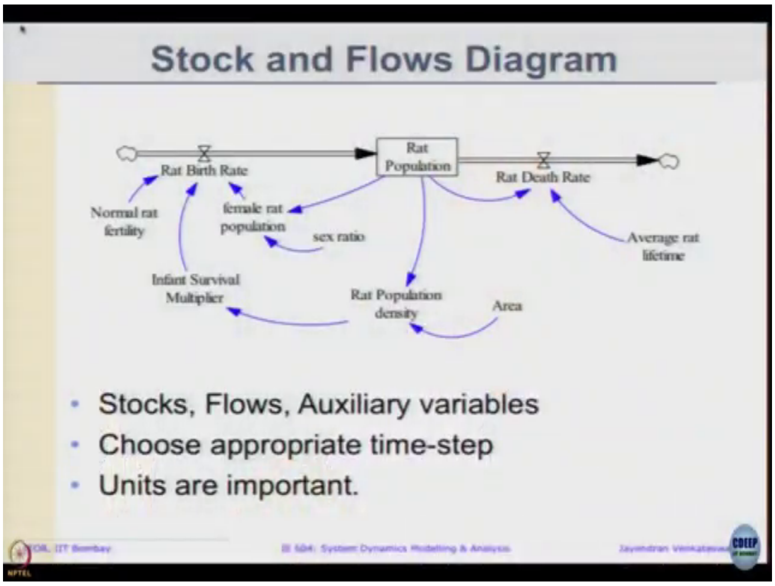

You can remember try to use noun and noun phrases, the action is already captured by the arrows that we want to that we have been using. But going from this to this that is a stock flow diagram, usually results in increase in the number of variables in the model at least to max the units you may need to end up having some more variables. Like for example, in this case so you see here just infant mortality here we are looking at female rat population, sex ratio, normal rat fertility average lifetime etcetera.

So, extra variables to come in; but this stock flow diagrams have been helping us doing the simulation, we had only three things stock flows auxiliary variables. Just three things stocks are usually physical or things we are going to use the information of decision making. Again if you take a snapshot or a picture of the system what we actually see there was this stocks, if you freeze the system in time whatever is left is the stock and stocks can only be changed to rates. So, do not be in any doubt which is the stock put in a inflow rate and out flow rate, we can figure out what the rate names is later I will just call it in rate and out rate you can always figure it out what it is.

Choose an appropriate time step sometime large time step cause unnecessary dynamics, time step should be at least one eighth of your smallest delay in the system to a yeah. Units are also important please make note and see what all because main thing I help of this units is it helps fix so a real. In reality if I want to measure it how will I measure it. So, this units allows force us to think in the terms and ensure that a model is valid and we do not end up multiplying things which or not to be multiplied and stuff like that wherever possible. Using these structure causal loop and stock flow models mainly stock flows for most of the semester.

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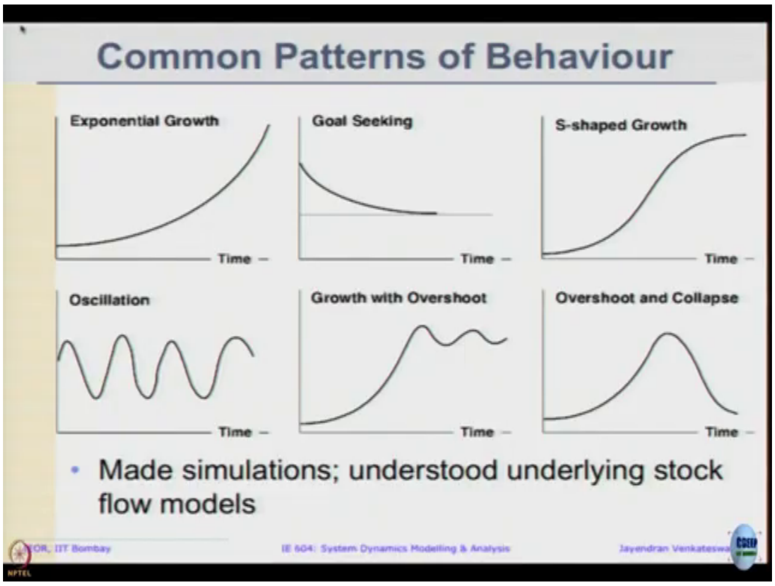

We looked at various patterns of behavior we looked at exponential growth goal seeking s shape, oscillations, growth overshoot, overshoot collapse we made simulations understood underlying stock flow models for each. Some are simple systems like exponential growth and goal seeking combination of that with delays causes oscillations, change in the positive and negative feedback system cause their shaped growths and more delays within those loops actually causes oscillations within the system. So, these are the things that we are actually seen with various examples.

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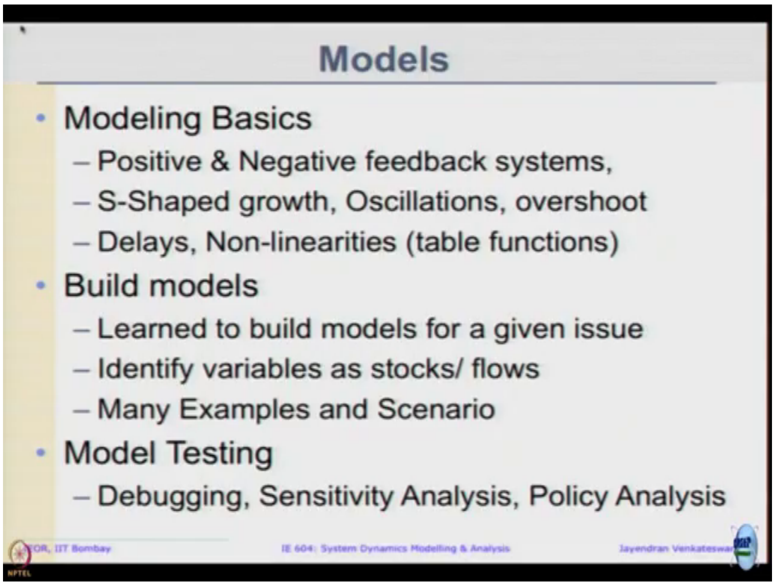

How you learn it was through various models? First we started with techniques like for example, we went through various modeling techniques and positive negative feedback system say shaped growths, oscillations, overshoots, delays non-linearities. If anybody is doubting did we really cover this we did trust me look at the videos later we have done all this. Then we learn to build lot of models we built models by using lot of examples rather, for given issue we identified variable stocks or flows.

We did many examples in scenarios we also learn to do model testing debugging sensitivity analysis policy analysis since some of these thing especial policy analysis has to be rooted in a specific problem or ratio, then we took up a few problems and issues to work with it. Debugging we took up some small models to work on the debugging issues. Sensitivity analysis refers to small change in the parameter settings or table functions or any of the model assumptions that you want to test to see check the limits of the model that is part we call sensitive analysis.

And policy analysis about a kind of intervention we have actually thinking of modeling ok. I am going to take a policy as for example, if it is potato price and doing the waive all the farm loans or should I give this minimum price and buy all the potatoes. What should be or should I give the incentive for the next round of crafts instead of this say ok. I will waive the loans of the next round of seeds or next round of plantation or fertilizer subsidy. Whatever those kind of decisions those are typically called as policies full circle.

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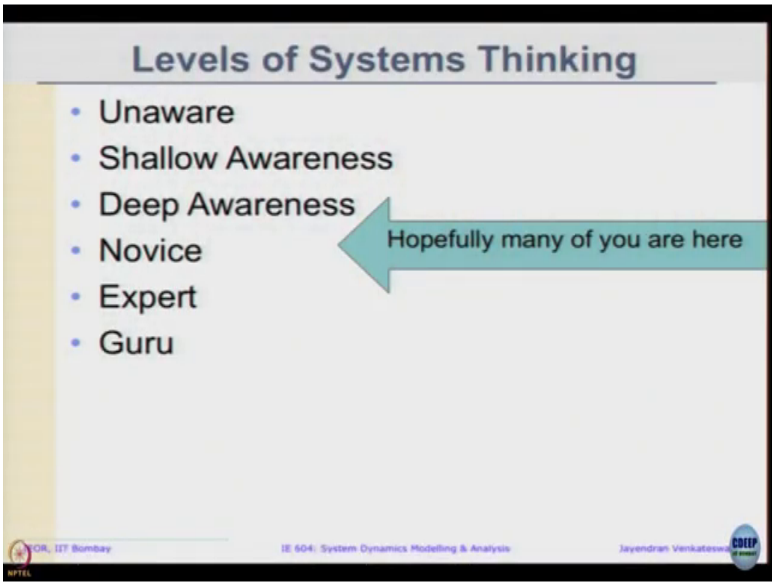

We are here various levels system think people have classified starting, with unaware shallow awareness, deep awareness, novice, expert and guru. Unaware you are no idea what system thinking was shallow aware is like you know some of the buzzwords, deep awareness is you can read the models and understand the results. Novice is when you start actually building your own models, experts is when you start building your own correct models and looking at open ended systems and trying to get what data and how to go about doing it.

Hopefully many of you are here this novice part we are able to actually build a model look at it definitely read models definitely understand what people are saying when they communicate. Look at the results in see what kind of systems structures may be underlying the phenomenon that we are looking at and then keep practicing to become experts I hope you are all here.

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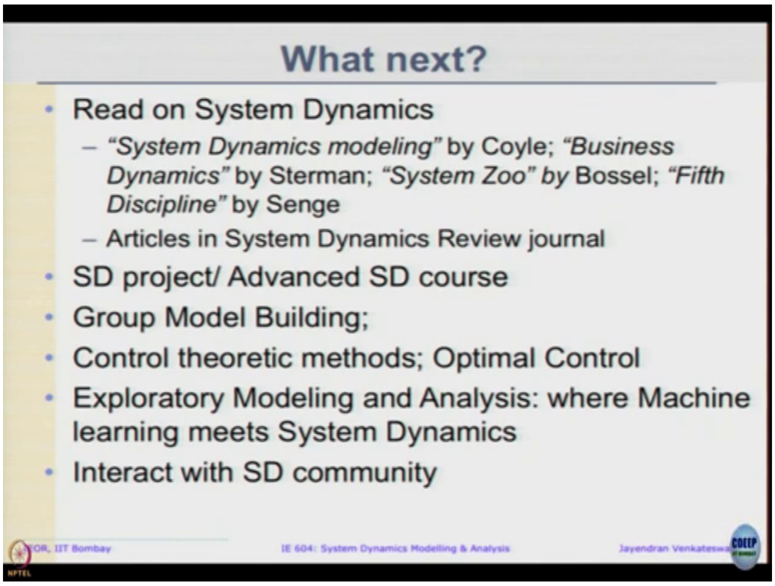

So, what next long term next not immediate short term? Read more on system dynamics if you are interested in this I hope some are this system is modeling by Coyle business dynamics Sterman there is interesting set of books system zoo by Bossel he has a what you call as zoo of models various scenarios fifth discipline by Senge. Fifth discipline is a what can I say it is a more light read there is not heavy equations and (Refer Time: 23:05) but he tries to present systems thinking more.

So, looking for journal articles system dynamics review is the (Refer Time: 23:10) journal here. So, lot of system dynamics were get published in this journal and there is also conference call the system dynamic society conference held every year, it happens in July. So, in the conference website they published a proceedings and many of them we published our papers as well as we upload our winsome models or (Refer Time: 23:31) or whatever the model file also. So, that people can download and understand it that is range of articles from teaching to implementing to really new once.

But if you want to move from novice and at least not regress back to a shallow awareness, you have to keep working on some SD incorporated part of a project or something. That you may work on try to do some advanced courses in SD or only we learn is to do a specific project or if you work on some specific project area. Then we can say they can use SD to look at it and then we learn through that under with some guidance the other notions in SD something called as Group Model Building.

Since many of the system is so large difficult one person to understand it. We need to go methodically in a as a group how we can actually model the entire system they talk to each other. We have all done group homework there it is not the same thing at all nothing compare to that we at actually get model working and working as a group, so two different things. The various notion the control theoretic methods in optimal control which can be applied here to the models that is something you might want to read up and learn and see how it can be used. Again as you told you underlying are all differential equations as somehow these notions are very useful in identifying a key variables and key point of leverage within our SD models.

Exploratory modeling analysis another big area which is coming up in the last 3 may be 5 years. This is where machine learning meets system dynamics again fantastic opportunity for people to do that because system dynamics with a so many policy settings and so many sensitive analysis. It can generate rich amount of data within machine learning can help us figure out and classify all our system behaviors to figure out where is the leverage points in a very systematic manner. That entire field is called as exploratory modeling and analysis. If you search for this particular phrase you may find select literature on that, yeah one of my PHD student Siddharth has also done some I mean obvious graduated. He has done work on this exploratory modeling for supply chain and healthcare and stuff like that. So, this is also there for reading.

Interact with the SD community as I told there are nice conference there is workshop that is held in India that are things happening, you might want to do that. So, yeah that is it questions comments these all we have done in the course.