Course on Decision Modeling
By Professor Biswajit Mahanty
Department of Industrial and System Engineering
Indian Institute of Technology Kharagpur
Lecture No 30
System Dynamics Example

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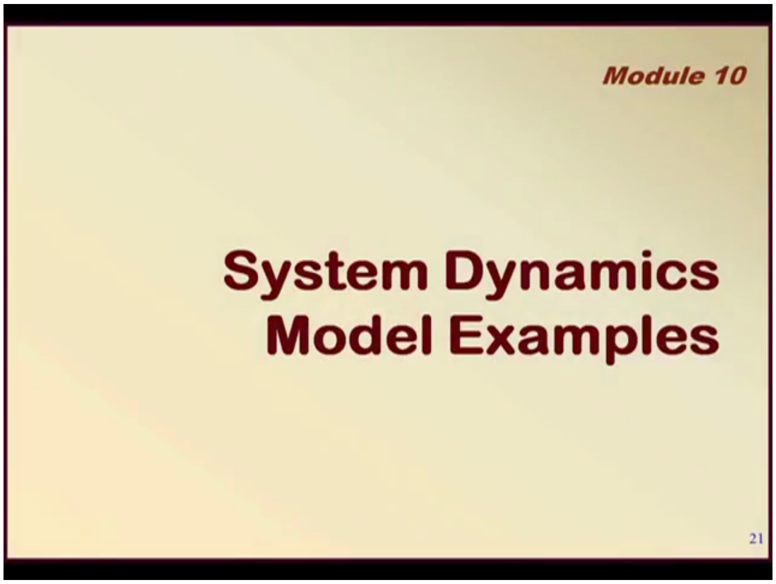

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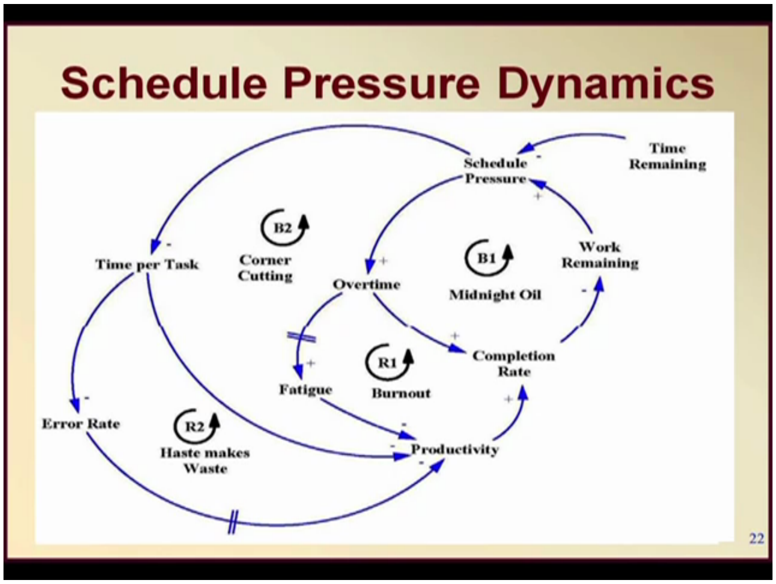

In our last class we have seen in the system dynamics you know and continuous simulation, today we continue with our system dynamics discussions. So earlier we have seen that we have the causal variables and here is a good example that is taken from the business dynamics book you can say you know a detailed example of how things can happen?

Let us say a project management situation, see in a project management situation what really happens, is that you know there is something called schedule pressure and why schedule pressure comes in? Because the time remaining is less, so more time remaining less schedule pressure but less time remaining more schedule pressure that's why is the minus. Now you see different loops can come in, so when you have a schedule pressure in a project, what you do?

Maybe you will go for overtime that is what is called by Sterman as you're burning midnight oil. So you go for overtime complete work faster your work remaining reduces and your schedule pressure reduces, right? So you burn the midnight oil but while you burn midnight oil there could be some people who can have fatigue after a time, right? That will reduce the productivity and that will reduce the completion rate, is it all right?

And then affect on schedule pressure and all that, so that loop is called the burnout loop. So the person goes out of the system and cannot contribute much, so that's the burnout. Sometimes what happens as you know have schedule pressure you give less time for task and that reduces your productivity, why? You know that's called corner cutting. So in other words less time per task more is the productivity, you do more work.

As you do more work obviously schedule pressure will reduce, so you go for corner cutting but if you go for corner cutting then you will make errors and as you make errors your productivity will reduce, please remember in project situation the errors could be very costly. When you make a mistake that mistake not only affects your current work but it might affect all your future work as well, is it all right?

So particularly in the software situation it may not be discovered and when it is discovered late it may lead to a lot of rework. So you know this is exactly what happens, the feedback dynamics is a reality and many societal situations say project management say other any kind of job that you and you know these kinds of maybe your project situations, right? So when you have schedule pressure you burn midnight oil, you also do corner cutting but if you do more and more midnight oil burning you may become a burnout or if you do too much corner cutting you may make errors and which will have serious implications on productivity.

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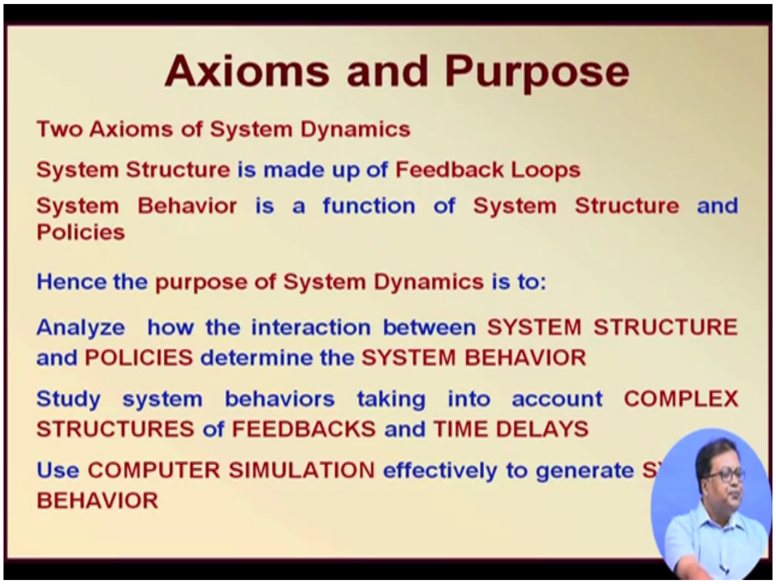

So these are other examples, now a little bit of theory you see there are 2 basic Axioms of system dynamics, what are they? The first one is called system structure, what is a system structure? The system structure is basically the kind of feedback loops that binds a system. Look at the population dynamics you know, if the birth-rate and death rate both are functions of population than that particular system has got a positive loop and a negative loop.

So it's a kind of structure, say not all systems which are having one positive loop and one negative loop behaves similarly. So structure is one thing the parameters and the variables how they behave? How they combine? How they interact with each other? That makes the structure but once the structure is built the behaviour is a function of that structure. So that's the second axiom.

The first axiom says that system structure is made up of feedback loops and second axiom says system behaviour is a function of the system structure and the policies. So once the structure is in place the behaviour is also known. So if you want to change the behaviour you have a system population is rising that is exploding, right? In fact you know even few years back the most of the world population situation was such the doubling time was not just constant doubling time was reducing and at some point of time it was something like 35 years.

So every 35 years the population was doubling which means in 70 years the population is 4 times, right? And in hundred years it could be almost 8 times, so that was the kind of alarming population increase that was taking place, right? So if you really want to control this population you have to change the structure. So that's what it says that behaviour is a function of the structure or intake policies, right?

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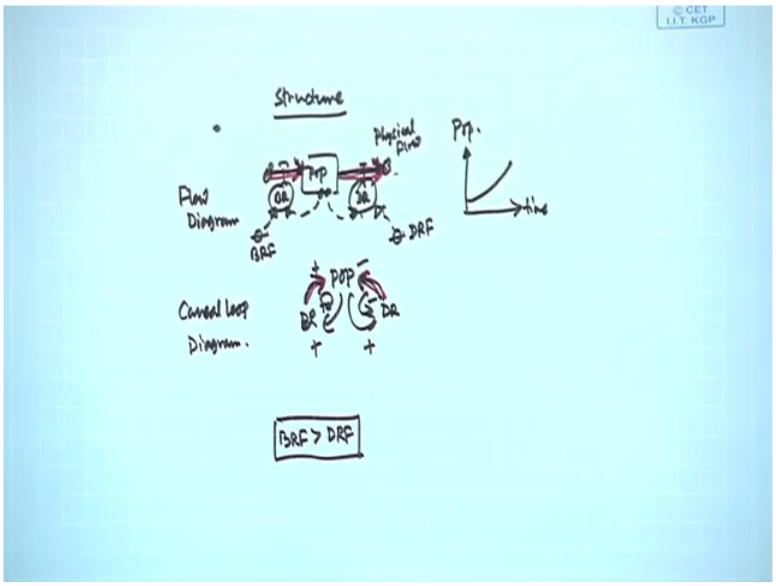

Change in the decision rules, so that's the thing that whenever simulating you have to structure, let us draw that suppose we have a structure, what is the structure? The structure is that here is the population, here is the birth-rate and here is the death rate, simplest very simple rudimentary population model, right? Here is the structure and here is the behaviour with time the population has a increase, exponential increase, right?

Why? Because if I draw the causal loop diagram then we have the birthrate and the death rate, right? So we have the positive loop and we have a negative loop here. So look here, one interesting thing that this part is the physical flow, this is a physical flow and that physical flow starts from a source ends in a sync, the source and sink are in finite reservoir and you know from the source the birth-rate is happening and from death, so as birth are happening opposition increases as death is happening population decreases.

So these are like rates and these are like levels and this level is also called a state variable, right? , this is called a flow diagram and this one is called a causal loop diagram. So we have a flow diagram and we have a causal loop diagram, so both are the same thing but one thing you remember the direction for the physical flow is here, here it is this way.

But here the physical is the outflow the flow direction is this but causal direction is opposite, right? So if I use another colour then you can find that these flow part this is the rate and this is the level, so they are corresponding, how they are corresponding? So this portion and this portion corresponding to this portion and this portion. So this is the inflow this is the outflow in case of inflow the direction is this way, in case of outflow the direction in the opposite way, so this must be remembered.

All other directions, now see the birth-rate is a function of population, death rate is also is a function of population, why? Not because it is a, I know it will happen all the time it is assumed to be happening in this particular situation and it is found to be true in most of the systems. So that is why we have taken it like that. So if it is like that then birth-rate is a function of population death rate is also is a function of population. So in that case we show in this way and that is how the loop is and this is the behaviour.

So as long as the structure remains like this, obviously I did not draw some parameters these there will be a fraction called BRF and there is a fraction called DRF. So obviously here it is assumed that BRF is higher than DRF for the country like India. The birth-rate fraction is higher than the death rate fraction and that is why the population shows an increase in trend but suppose the reverse happens, suppose DRF is more than BRF then the negative loop will take over, right?

And population will instead of writing it will start falling. So you see one is structure another is this parametric values and there could be a policy, suppose policy could be reduced the birth-rate means reduced BRF, if I can reduce BRF obviously we can change. Now how BRF could be changed or DRF could be? See it is not good to say that it has increased DRF that is not possible the DRF has to go down, right? Medical advances and everything should reduce the death rate fraction.

You see what we can think of? We can think of food availability, right? So food availability, resource availability and housing availability all of these as direct bearing on BRF, so that may create further feedback loops, right? So we can make a bigger and bigger model we can look at various other kinds of things and we can start making those kinds of calculations also to really see their effect on BRF and DRF, those we are calling policies.

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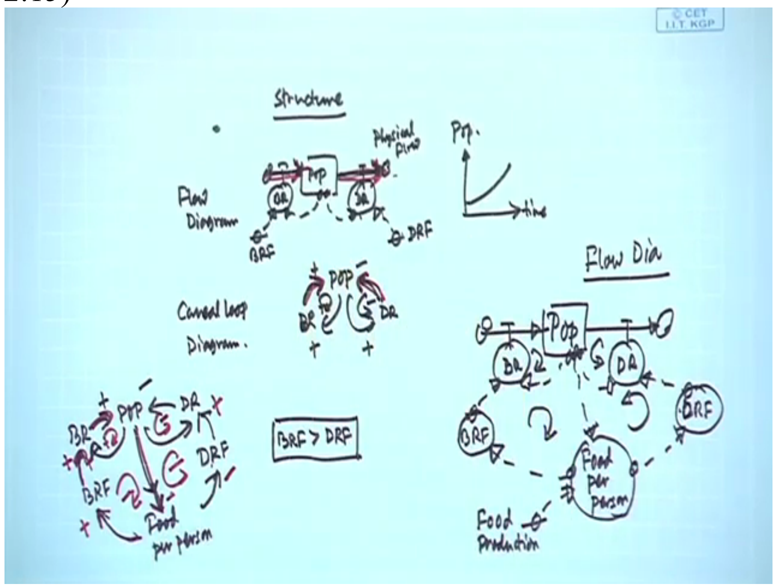

So as you make those policies newer feedback loops will be joined here, how it will be joined? Let us take one example, suppose this is population then we have the birth-rate and here we have the death rate and we are saying that the birth-rate fraction and death rate fraction, obviously they may not the constant anymore DRF both are, that's it. Now suppose there is another variable called Food production, for the time being let us assume it to be a constant.

So food per person, this is another variable and which will be, because it is per person so it is dependent on both population and the food production. This food per person may have an effect on the death rate as well as on the birth-rate, alright? So you see we now have another loop here and another loop here. So apart from the loop that we have here and loop here although it is in these the causal direction is on the other side.

So this is our flow diagram and the BR, POP and DR plus, minus. BRF, we will not put the directions but we know that food per person depends on POP and this one and we have this. So look here we have now several other loops, 2 more loops at least are created more population less will be the food per person and less is the food per person, let us assume that more population less is the food per person and more food per person more birth-rate.

More birth-rates, more birth. So you see apart from this is a plus loop but this one will be a negative loop. So more food per person less will be death rate and more death rate more deaths. So you see this side also minus minus minus there are 3 minus, so odd number of minus signs makes a negative loop. So here also we have a negative loop and we have a negative loop here anyway we have discussed.

So you see we have only one positive loop and 3 negative loops. So moment you make that food per person concerns and if we make that if food per person reduces it will have an effect on the birth-rate this is not right that will make a bigger analysis and we can see that when the structure is in that way that means as long as the food per person is not a concern, in a food is available, right?

Then the population increases in an exponential manner but moment the food comes into consideration maybe for a rat population you will find it will have an effect on the population, it may not grow exponentially anymore. So such kind of analysis can actually be obtained and we can here we have just deal a qualitative analysis but in reality we can actually do analyze how structure, policies and behaviour are interacting and we can look at the complex structure of feedbacks and time delays and used computer simulation, right?

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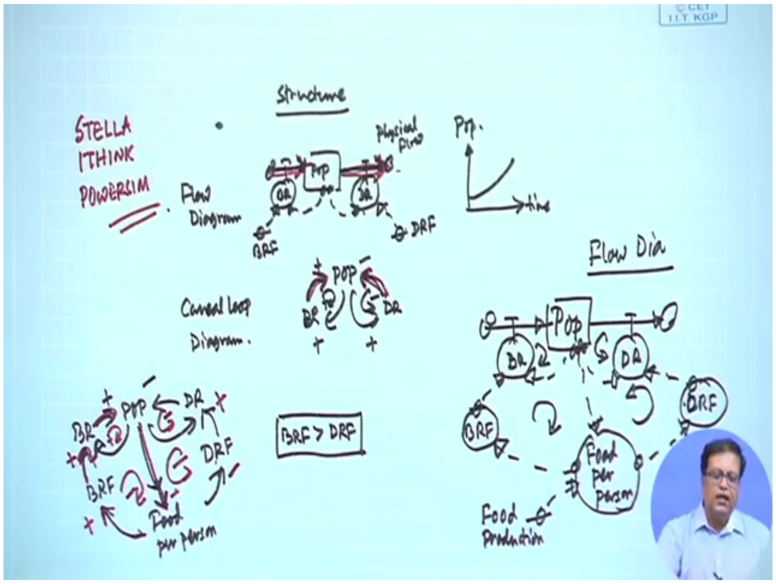

There are several software’s that are available like Stella like I think like Power Sim, so all these software they can help us in doing what is known as the simulation, computer simulation and generate behaviour with time.

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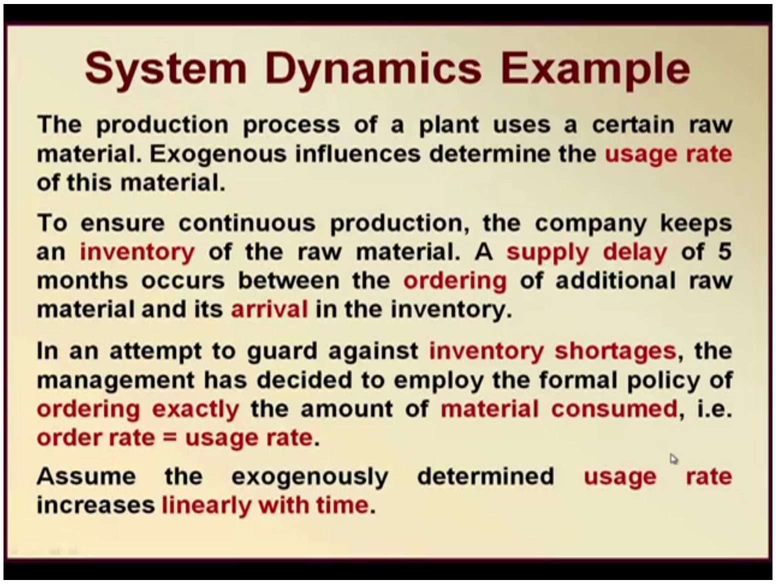

So let's look at one more example the production process of a plant uses a certain raw material. Exogenous influences determine the usage rate of this material. To ensure continuous production company keeps on inventory of the raw material supply delay of 5 months occurs between the ordering of additional raw material and its arrival. In an attempt to guard against inventory shortages the management has decided to employ the formal policy of ordering exactly the amount of material consumed that is order rate equal to usage rate.

Assume the exogenous leader mind usage rate increases linearly with time. So what happens there is a usage rate of a particular item and as you use the inventory of the stores goes down. So what you do? Exactly the amount you use the same amount you order but as you order the material does not come immediately, it comes after sometime. So it remains in transit and then the material comes after sometime. So a delay process is involved, right?

So how do you go ahead with this kind of situation? So let's look at the flow diagram, the flow diagram will be like this. You see we have an order rate, as you order the material comes there is an incoming rate that is a delay, there is a supply delay so incoming rate will be a function of material arriving and the supply delay. Material arriving is like that amount which is in transit, is it not?

So this is a state variable or a level variable whereas the inventory is the material that is the store. So material that is incoming to the store it will go into the store and then finally as you use the inventory material will reduce and then order rate is taken as a function of usage rate. So this is our flow diagram.

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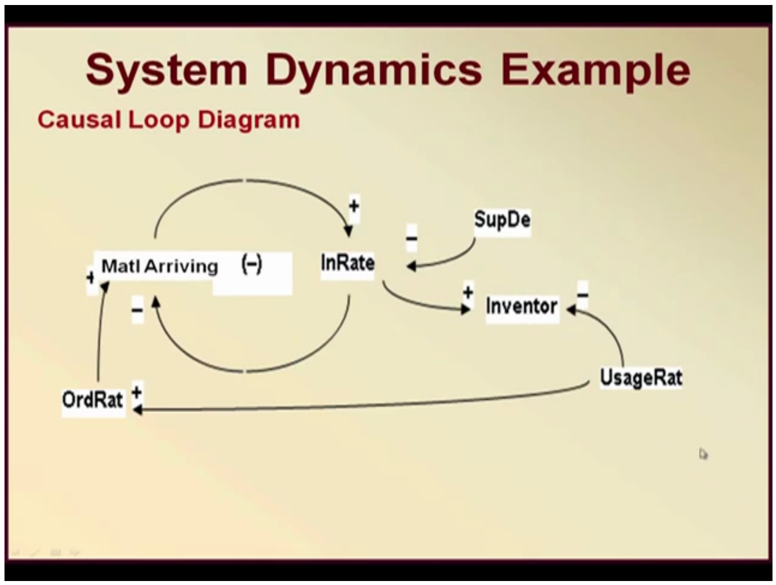

Let us look at the causal diagram, the causal diagram will show as you order the material arrives, as material arrives the inrate will be. You see there are 2 equations, one is that material arriving and incoming rate is an outflow of the material arriving. It is not incoming rate for material arriving it's the incoming rate for stores, is it okay?

This is like material shipment rate you can call. So this is the, you know outflow, so the causal direction will be negative. So this is the physical flow path, so as the material is incoming the material arriving reduces. In simple terms more material comes to store, less will be the material in transit but more material in transit more will be incoming rate because there is a supply delay that delay will be taken also.

So here the other way round is more material arriving more will be inrate and more inrate more inventory, more usage rate less inventory and the policy says the ordering rate is exactly same as usage rate, right? And the supply delay also affects inrate. So that will be calling our causal loop diagram and there is a negative feedback loop here that is a system.

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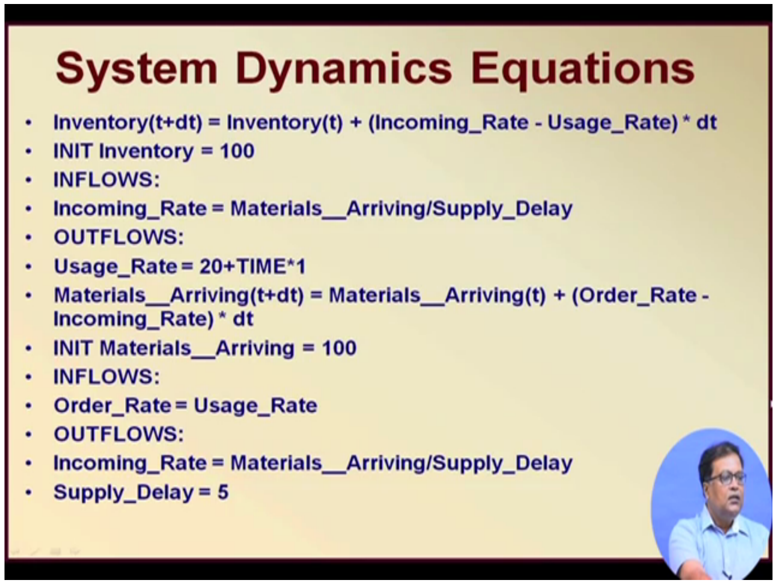

Then let us look at some equations, so these are the system dynamic equations that you have inventory t plus dt as I told is inventory t plus incoming rate minus usage rate multiplied by dt because inventory in rate and usage rate and inventory initial 100. Incoming rate materials arriving rate by supply delay. Outflow rate usage rate is taken as some functions, right? 20 plus times star 1 it's an increasing function.

The material arriving t plus dt is the other what is known as the level variable, material arriving t plus order rate minus incoming rate by dt. Material arriving initially is 100 and order rate equal to usage rate that is the inflow and incoming rate is material arriving by supply delay, already given. So this is the inflows for you know inventory and this is outflow for material arriving, the same equation is given twice. Supply delay equals to 5.

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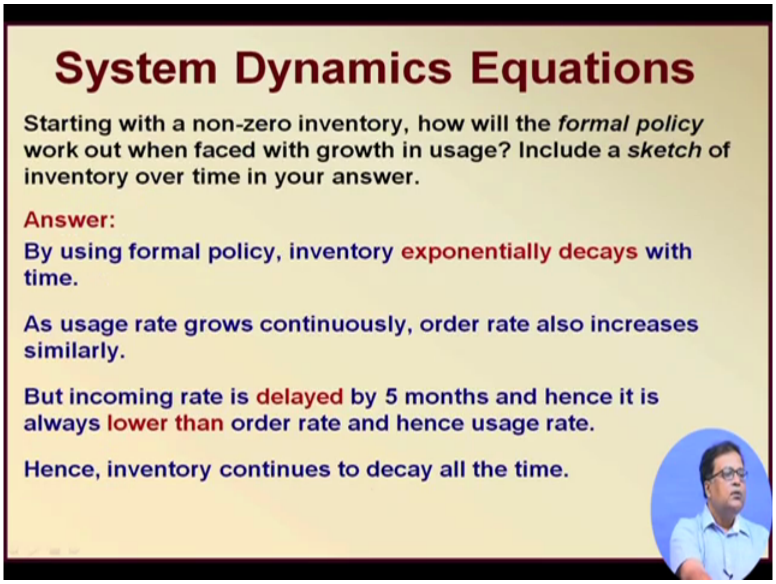

So starting with the nonzero inventory, how will the formal policy work out when faced with growth in usage? See what is the policy? Incoming rate equals to usage rate, so inventory exponentially decays in time, why? That is very interesting as usage rate grows continuously, order rate also increases similarly but incoming rate is delayed by 5 months and hence it is always lower than the order rate and hence the usage rate. So therefore inventory continues to decay.

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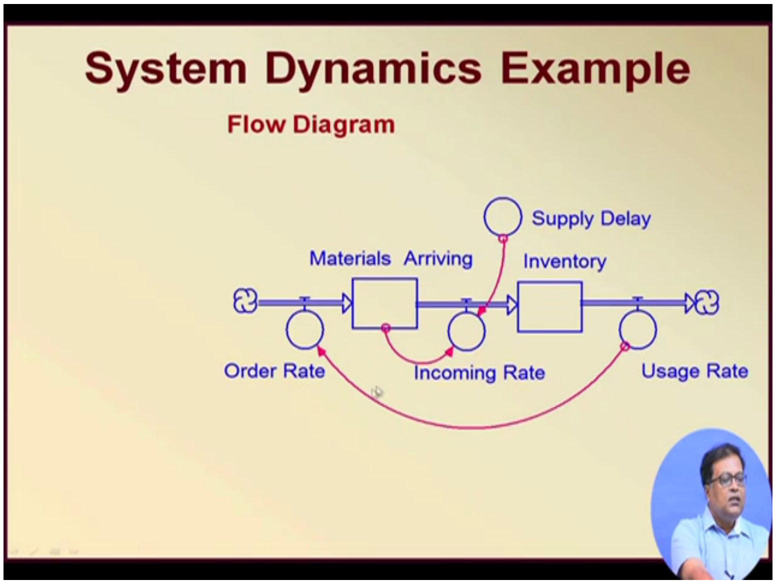

Look here what is happening? Look at this diagram, you see as you order after sometime incoming material comes, as the incoming material increase a store usage rate decrease a store. Initially assume all are equal, alright? And then usage rate increases, as the usage rate increases you will immediately order that much. So suppose this is 100, 100 and 100. Now this becomes 110, as it becomes 110 but you order, now order is 110 but what you're getting, 100 the old one because there is a delay.

So this delay is how much? The delay is 5 months. So till 5 months you'll get the old rate that is hundred, so incoming hundred outgoing 110 so there will be a gap of 10 and by that amount the stores are going to be reduced, right?

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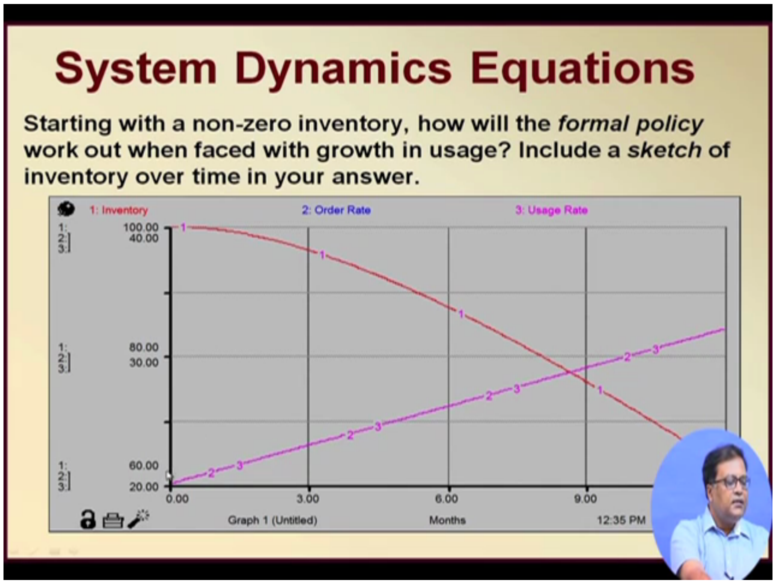

So look at the plot, so as the usage rate increases this is 3 it's usage rate, 2 is also order rate, this is the plot, this plot says that both usage rate and order rate increases but what happens to the incoming rate? Incoming rate also increases but there is a gap and therefore inventory will keep on falling. So that is the system dynamics equation, alright? So what we have found is that, this particular model you know the behaviour really changes based on deserted incoming condition.

And that condition was that in this particular model, since there is a delay involved and if they are ordering, how much you order? If it is simply the usage rate that after sometime system or the stores actually goes to 0 and as a store goes to 0 you cannot use anymore. So what you should do? The essential idea therefore is that you should order more not only that the order should look into how much to order?

You should look into the inventory and not usage rate alone, right? Or in other words your ordering policy should be not only a function of usage rate but it should also be a function of inventory, right? Maybe inventory Gap, when you do that only then you can have balanced inventory situations.

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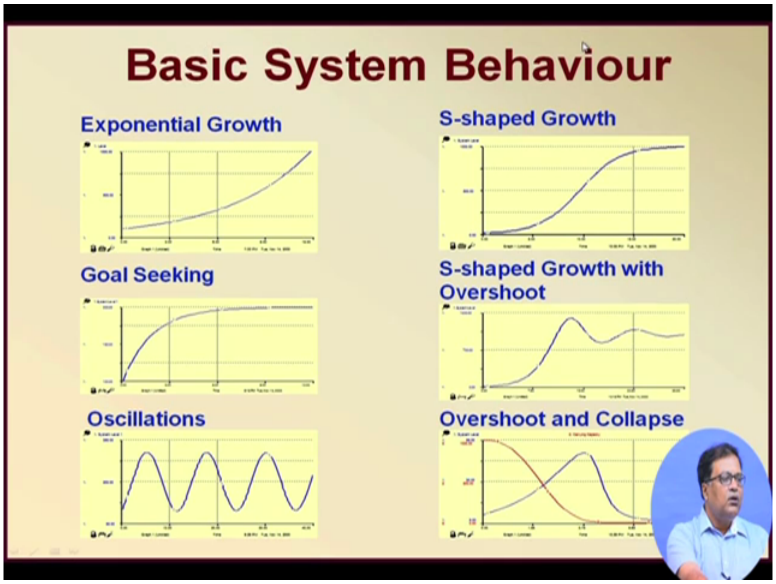

Now here you can see some of the important plots about basic system behaviour. So what are those basic system behaviours? They can have an exponential growth, we can have an S shaped growth, V can have a goal seeking model, we can have an S shaped growth with overshoot, we can have an oscillatory remodel and we can have an overshoot and collapse model, right?

So look at it more carefully, this is the model which is called the so-called positive feedback loop behaviour, right? That is when like in population where birth-rate is more than death rate. So your behaviour will be continually rising. This is the negative loop behaviour, so if there is a controller then it will try to keep that variable to a goal seeking model but sometimes the controller may be there but it may oscillate around a certain you know frequency.

But when you have both positive as well as negative loop like the population model discussed we can have an s-shaped growth, right? It grows initially very at high rate and later on it stabilises to certain value. On the other hand if there are delays in nonlinearities then we may have an S shaped growth with overshoot, right?

And finally there could also be a model where we may have an overshoot and collapse model, not only it overshoots but it goes to a 0 value. So all of these are some basic system behaviour and actual system behaviour could be a function of all of these together. So what is it that we have to do in a system dynamics model? Not only we have to know that all these different behaviour modes are there, we have to come up with a specified specific system structure, so that with policies and with our basic knowledge of the different behaviour modes we can actually generate a particular kind of system behaviour by a certain amount of scenario analysis, right?

So I stop here there are much more about system dynamics, if you're interested you can go through the book by Sterman or any other good literature on system dynamics, is it all right? Lot of material is also available on the Internet in MIT site, so thank you very much.