Introduction to System Dynamics Modeling
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Lecture – 14.1
Delays
Modeling Delays: Material Delay

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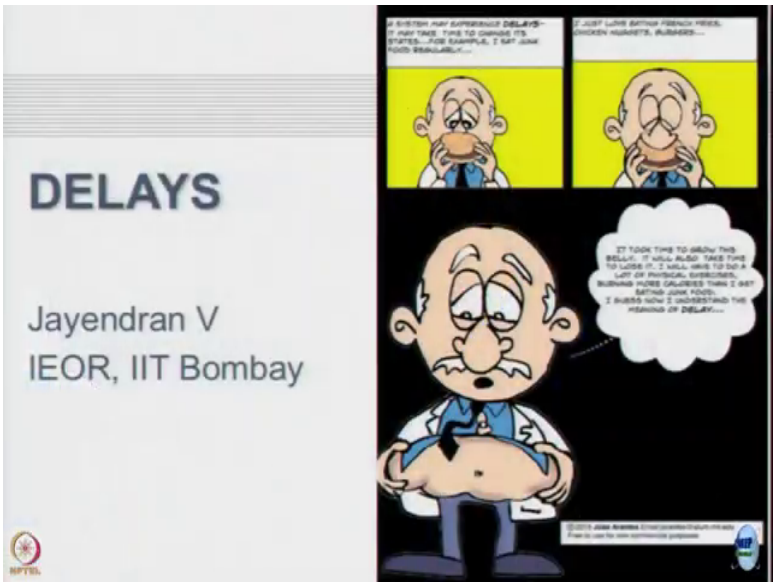

Today, we are going to be looking at Delays. So, how to model them in system dynamics, what it means?

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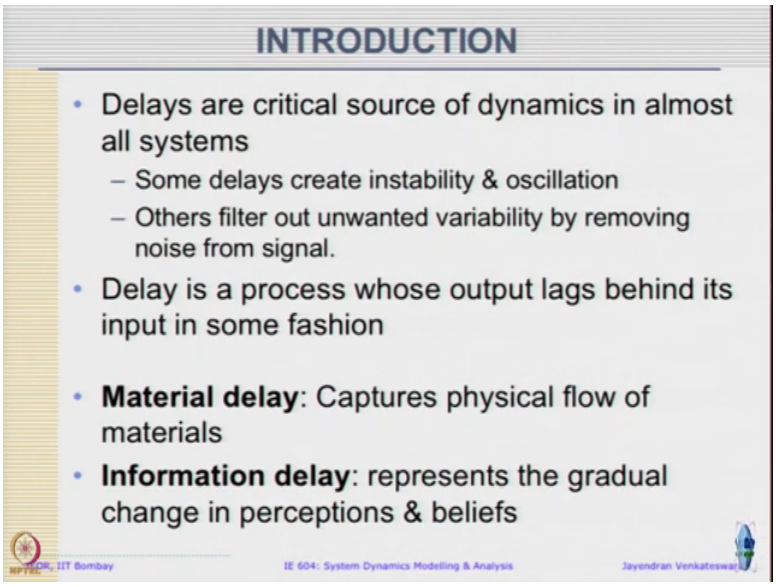

So, delays exist in almost all the systems ah. Some delays create instability and oscillation; others filter out unwanted variability within the system, so that we can get rid of the short term variability and look at the long term performance or remove noise from the signal. So, these are this aspect in all the systems and whatever process we take there will be some form of delay, which is inherent part of all the systems. If we just think about it in modeling perspective delays are nothing, but where the output lags behind its input by some time duration right whatever it may be ah. So, that is a very simple definition of delay.

So, broadly speaking, we can think of two types of delays; one is called as material delay which captures a physical flow of materials. For example, if say we send in raw materials into the factory after a time delay of say 2 days it comes out as a finished product as raw material comes in maybe after 2 days it comes out as a car. So, there is a delay and there is a material is conserved. So, whatever material goes in, which either comes out as a finished product or

as a scrap right. So, there is a kind of a mass balance. Or you can think of say letters that is being posted say through courier or postal service.

So, what all goes into a system then remains in transit for some duration of end of it which it is delivered. So, those are material delays, where the material gets conserved and or when you send an application for say applying for IIT. Your application was a physical material it went to the admissions office, it stayed there for some time, many different people would have processed it and then finally, you would have got some response to that correct. So, those are also material delay. Or when you finish an exam you give the exam papers to me, then I have to grade the papers and give it back. So, even those are also considered as material delay.

So, material does not mean it has to be a physical you know object or anything it can also be like an order or the exam papers etcetera. So, those are also material delay. Or act of sending an emails. So, when you send an email assuming nothing is lost, but after some delay the material gets read. So, until you read it the material is in your inbox, even after that it can go into our archives or it continues to remain until you delete it right. So, there also the material is conserved. So, those are all considered as part of a physical flow of materials. So, I am just having a very broad description of the physical flow.

The second kind of delay is called as a perception delay or information delay, which represent gradual change in perceptions and beliefs; even change in beliefs is going to take time. So, these kind of delays are called as perception delays or information delays or delays of beliefs. This is also quite interesting; given a certain peoples background a certain kind of kind of perception about things. You cannot just pass a law and make it change overnight. It takes some time for it to gradually change in especially in social customs.

Another more related information delay could be how you process whatever has been taught in class right. It takes time to absorb it if at all at some point some amount gets absorbed it takes some time to retain it and over time that can also we tend to forget know like. So, those are called as information delay. So, there is no conservation of mass. It can be like you know I

taught you so much hours of material and that much hours gets stored in memory, it does not happen like that right.

It is a maybe some few abstract pieces of information that gets stored which also erodes or gets updated over time right, when you get new information you process new information and the old one either gets replaced or reinforced or you just forget. So, those kinds of perceptions is what we call as information delay. Some form of both you might have seen in other courses also.

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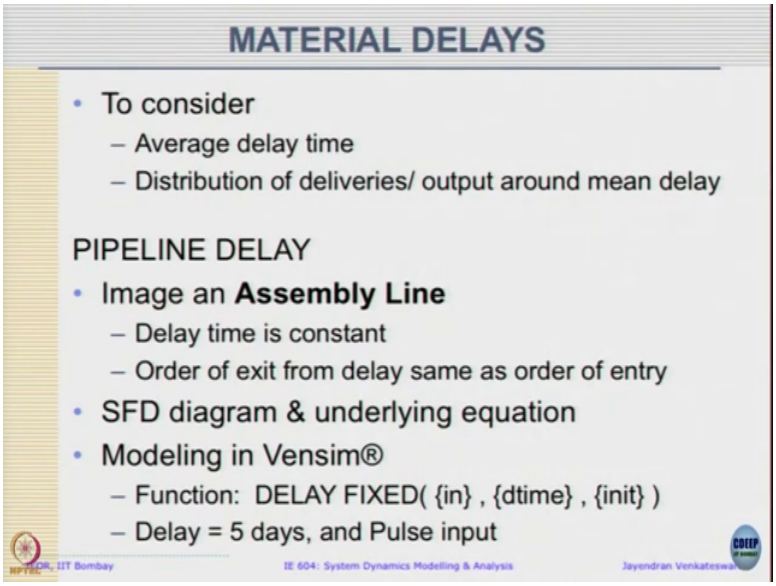

Today's class we will start with the material delay which is kind of more easy to grasp and handle will get a hang of that. So, material delay – so, whenever you look at material delay essentially in modeling system dynamics method we consider two things. One is average delay time other is distribution of deliveries or output around this mean delay.

Like as I told example of sending letters, I send letters and after a delay of say a week or a week suppose all the letters are delivered exactly at the same time then I know that there is a fixed delay right, but it does not happen so. Sometimes when you post a letter today some letters get delivered after 3 days, some after 4 days, some after 5 days right. So, there is a distribution around this average time of delay.

So, those are two things that we want for modeling the delays. What is that average time and what is the distribution around that average time that we expect and based on that we will be choosing the kind of models we want around that. Let us take the simplest case saying that where output lags behind it is input by a fixed; that means, constant duration we call that as a pipeline delay.

So, whatever you send in at this end of the pipe comes out at the other end of the pipe, the same quantity after fixed duration ah. So, it is a very common in like say an assembly line kind of setup where material is sent and after a time a finished product comes out whatever the timescale might be. An order of exit from delays also same as order of entry, delay times are constant. So, this is one of the simplest model.

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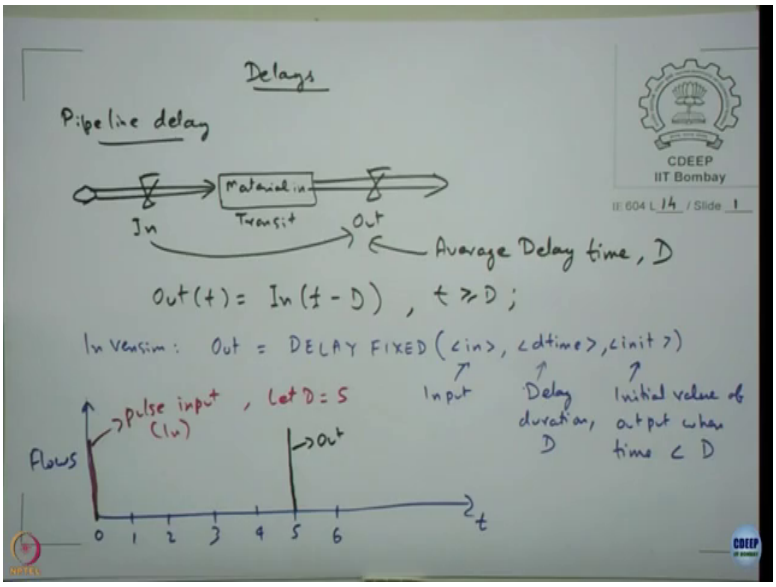

So, let us give delay as the topic; let us consider a simple pipeline delay, we represent it as see imagine again letters being posted. So, we can consider it as material in I drew a two small box, but you can correct it is in is a outflow average delay time D. So, we are going to be using capital D for the average delay time throughout. So, input is kind of exogenous so, whatever it can be; material in transit is nothing, but the difference of the flows. So, only equation of concern is what is his output. So, output time t these are nothing, but inner time t minus D.

So, very simple equation output lags behind input after D time periods. So, in Vensim if you want to model it, we can write these equations as you have might have observed in Vensim there is no way to give a subscript of time t time t is taken as implicit right. So, they have to find functions for that. So, if you want to model this in Vensim out is simply modeled as there is a function called as delay fixed. It takes as parameters in dtime init. There is in, in refers to

your in flow or the input dt is your delay time D, delay duration and init it is the initial value of output when time is less than D or the delay duration.

So, these are two or three input parameters for this function which fully captures this. So, now, internally what Vensim will do is do the same equation output as in of t minus D where D is your delay duration and in the first you are in here which is same as in here. It is a variable name and init is initial value. If you observe the equation when t is less than D it becomes negative. So, we need to know what happens when t is less than D. So, that is also specified in Vensim's what is the initial value, typically we take it as 0; that means, there is no output until actually input starts working. So, there is a simple lag.

So, you want me to write a proper equation. So, this works when t is greater than equal to D, yeah that is it. It is quite simple to visualize your flows. For example, if there is assume a pulse input at say time 0; at time 0 there is a pulse input and assume there is a D equal to say 5; that means, that after 5 periods the entire thing is going to come out as an output. So, this becomes your out, this pulse input is your in.

It is very simple delays order you are going to put in is going to come out. So, whatever profile it comes here this is going to be offset by D time units and the same profile is going to come out after D time units for the output. So, we look at few types of delays then we can move to Vensim for trying it out it is not that difficult look at it. So, this is what we are seeing. So, this one extreme or whatever you do after time delay starts coming out, we can take the other end of the spectrum a kind of delay which we have already seen.

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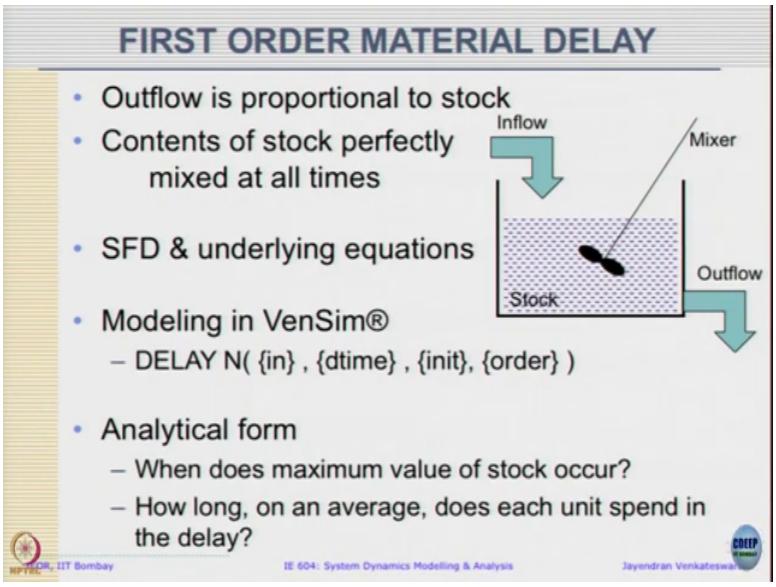

Since you are looking at delay I am delaying it as a first order material delay. What you are saying is in this case output is proportional to the stock. So, assume that whatever inflow occurs the stock is mixed perfectly; analogy here is again the same water tank.

So, this water tank as you can see there is inflow happen and supposes a tap below, it is not water is not going to follow first in first out policy, as soon as it comes in it is going to be assume there is also a mixer which keeps mixing it.

So, water is going to just come out almost instantaneously as long as inflow started immediately outflows will also start and tank will continue to drain in this model. This is nothing but a simple first order model that we already seen you know when there is a outflow

which is proportional to the inflow and the stock in hand. So, tank is going to keep draining until the entire tank is drained right.

So, that simple first order negative feedback system is also called as a first order material delay. We will do the Vensim one and couple of questions we can think about. If if it is a first order material like a first order negative feedback system so, whatever inflow occurs and the system starts draining almost instantaneously. So, what time does the maximum value of stock occur? Will be a time 0, will be at the initial point how long and average it spends.