Introduction to System Dynamics Modeling
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Dynamics of Stocks and Flow (Contd) & Patterns of Behavior
Lecture – 6.1
Stock & Flow Diagram: Basics-III

Let us get today's class started. So, we will continue to look at Stocks and Flows.

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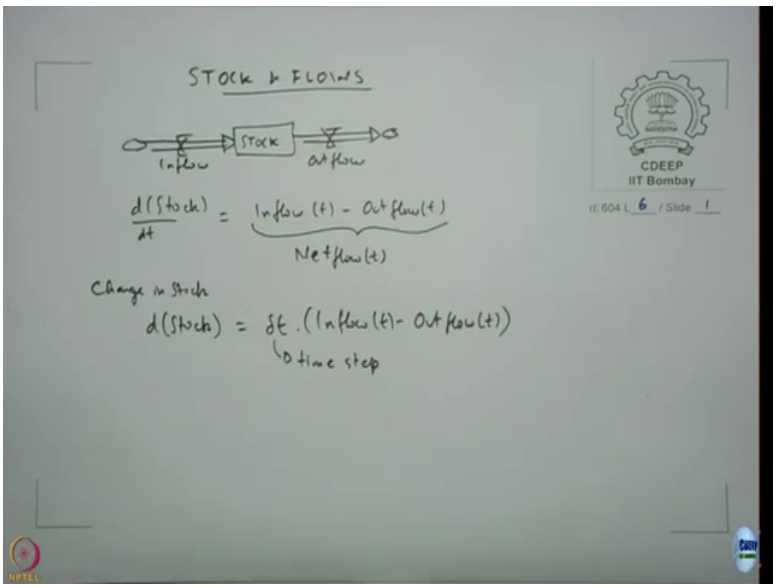

Yeah. So, introduce you to the two key concept of building a system dynamic model which is identifying your stocks and flows. Stock is represented as a rectangle and flows are represented by thick arrows with valves in it. Direction of arrows shows whether we are adding to the stock or removing from the stock. And, what are we adding we are calling it as inflows, whatever we remove we are calling as out flows. And it is important to note that the

underlying equation to this graphical representation is nothing but a differential equation rather change in stock overtime t is nothing but inflow minus outflow.

This is also known as net flow at a particular point in time. If you want to actually see what is the say change in stock; so change in stock, that is d of stock can simply be delta t times your inflow at time t minus your outflow at time t. And when we are actually saying trying to simulate it what we are, so this dt represents your time step or time yeah time step or time interval, measuring the change in stock during that particular time and that is amount of stock that is changed from its previous value that is amount added or subtracted from the stock.

So, let us try to look at an example and looking at a description how to identify the stocks and flows and construct a diagram looking at stock and flows. So, then today's class we will say that if the inflows or outflows behaves in a particular fashion over time, let us try to graphically figure out how the stock changes over time, so we get a feel of how the simulation itself is expected to work.

Because, many times what happens is when we start moving get equations we kind of just blindly trust it and, but before that we need to build intuition the best way to do it is graphically and trying to see what kind of behavior we can expect over time. So, that is agenda for today's class first part of the class. Let us move on to the examples.

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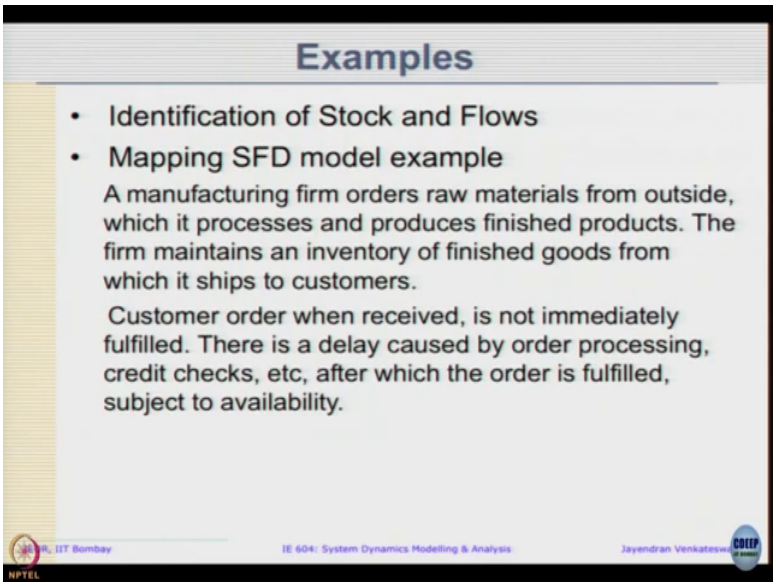

Let us look at a scenario where you get few examples last class identify stocks and flows. So, today we will begin with an example of just mapping the stock flow diagrammatic representation of a model, ok. So, the description, using the same description, you can model a causal loop diagram we have seen some examples of that last week. But, we can go one step further and start to identify what are the stocks and flows within the same based on the same description. Let us take a very most straightforward example where many things may be physical.

So, let us start with that. The manufacturing firm orders raw materials from outside, which it processes and produces finished products. The firm maintains inventory of finished goods from which it ships to customers. Customer order when received is not immediately fulfilled.

There is a delay caused by order processing, credit checks, etcetera, after which the order is fulfilled subject to availability ok. So, this is the very brief description.

So, what all could be the stocks in this model in this scenario. I think the example is quite easy to remember all we have is; I mean, company gets raw materials then it produces and make finished products. And when customer makes an order, they keep it in backlog and while they are doing all the various checks. And then once it is done it shifts.

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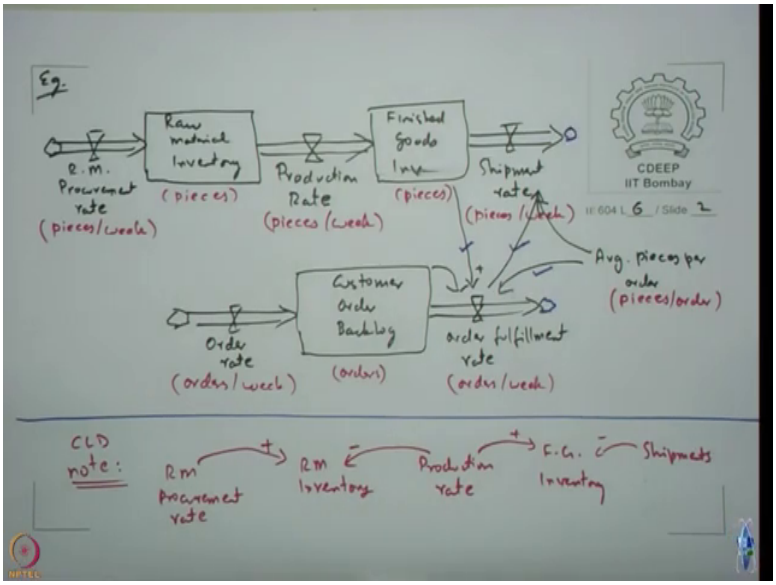

So, we identified three stocks, raw material inventory, finished goods inventory oops, then let us have something called as customer order backlog. So, this is the example. So, these are three stocks we have, and the description starts out saying that manufacturing from orders raw materials from outside. So, we can or rather we need to have a flow which is coming into the raw materials right, otherwise how the stock going to change. So, we need to have a flow we

cannot have anything else we have to have a flow, so that will be the rate at which I am going to be procuring materials.

So, I can call it as I am using R M for raw material procurement; procurementary. And raw materials I am going to use the raw material to make the finished products right. So, logically there must be some production process that is happening which converts these raw materials into finished products. And based on and there are still some conservation right, where based on the raw material use I produce finished products.

So, I can have a single arrow like this, hold as production rate. Again, note all arrows need not start with the cloud. Cloud means it is like an infinite source whenever I order it keeps coming, is almost it is any kind of case in this model looks exogenous. For production rate, it is going to remove material from the inventory and add them to this finish good inventory. So, it is going to remove.

So, material in that way is conserved that was one of the states we told for stock it gets conserved. And from the finished goods, we going to have something called as shipment rate. Just observe how I have given the variable names, whenever there is a flow we just told flow or rate or flow rate just to ensure that we do not make mistakes and units, we can always say RM procurement rate, production rate, shipment rate, or you going to just use the word shipment or production, but then we get confused as a unit. So, it is always good to write shipment rate.

So, whenever you say rate that means, units over time all right. So, it helps us doing that. So, also good to think in terms of some of the units, so procurement since no other information is given just for example, we can take it as a pieces per week could be the units here. If this is a units here, then the same units has to be here, you cannot have any other units has to be pieces per week.

And I am arbitarily chosen the time units as week if day then make it transistent using day, then the raw material units is pieces, inventory unit is also I am counting in pieces. But, if you measure in tons, you use it tons; if its kilogram, use kilograms consistently whatever the

units. If it is in cases or if it is in some sort of stock keeping unit, then you are use the same units appropriately. The idea here is rates as there is per unit time and others it just has pieces. So, this is a physical flow of the material that we have captured.

The second part of description dealt with the information flow, ok. So, what we have is customer order that is backlog what we have is customer order rate. So, as more orders come in, the backlog is going to increase, so we can just call it as order rate, and as we start fulfilling orders that orders rate is going to go down. So, order fulfillment rate is rate at which orders are fulfilled. Just a side note, it is called a CLD note. If the same thing I want to represent as a causal loop the top part, how I will write is like this, RM procurement rate, then let us call it raw material inventory, and let us call it production rate. I am just going to give one example you can extrapolate it is for others.

So, here as raw material increases, my raw material inventory is going to increase right. So, direction is the same. So, I get an arrow like this, but its production rate increases the raw material inventory is going to fall down, because I am going to consuming the inventory. So, the direction of arrow will be like this.

So, when you see descriptions like this, so this negative arrow I mean the arrow with a negative causal direction, this is denoted by an arrow outgoing arrow here, ok. So, you can see this image contrast with this. We will get similar thing here like order rate, customer order backlog, order fulfillment rate exactly similar like here is right.

See, I want to add a finished goods inventory, the production rate will have a plus sign to finish goods inventory, and then it will have a like if you want to have a finished goods inventory shipments. So, this exact causal link of this one, but this when will start moving to casual the stock flow diagram, it capture some more information that is the flow of material is conserved here automatically. But here, it looks like production rate is I can have a very different equation for inventory and this and it can affect both in a different ways right that is not very intuitive here.

So, when we do it here that grounding little more into what actually happens? Let us go now back to the stock flow diagram. So, I will just trying to illustrate how the CLDs can be translated into stock flow. Now, this model is not finished. One way to check that is how we are getting the order rate just to make our lives little more interesting.

So, order rate, suppose we measure it as orders per week. So, then this has to be orders. This also has to be orders per week. This flow is now conserved. This also orders per week, this orders is this is also orders per week there is the unit of measure I have, but now I have to link these two as shipment rate and I have an order fulfillment rate where the units do not match. So, I cannot just say that the order fulfillment rate equal shipment rate and model the equation what else what do we need. The average size of an order or average number of pieces per order, this is just a simple variable I need based on which I can link these two, ok.

So, I can have a another variable called as average pieces per order. So, now what all should I link; now, will intuitively what we expect to do. We are going into the equations (Refer Time: 13:40). Say every week imagine what do we do I look at the backlog this is a backlog I have, then what is the average number of pieces that it demands this is the total pieces I need. When I look at the inventory to have enough piece and based on that I decide how much I should ship correct.

So, to decide on the order fulfillment rate, I need information about say the customer order, average pieces as well as current inventory, right. If inventory is more my fulfillment rate will be higher, so I can have a plus these are anyway some constants. So, I got an order fulfillment rate. And based on whatever the order fulfillment rate, the same rate I will do the shipment. I can add any questions simply setting shipment rate equal to order fulfillment rate or something; the two arrows here one as shipment as well as average pieces.

So, this, this arrow here represents that customer order backlog information is used in computing order fulfillment rate. So, this thick arrow only indicates that backlog users this information of customer order fulfillment. This thick arrow only represents this line ok, I have not drawn only represents a line between order fulfillment to customer backlog.

So, they want that other line, I have to draw it explicitly. But to start with it is what this going to equations, you will automatically start doing it system will prompt you that you connect the arrow for you. For now all you have to understand is we had defined two stocks and flows, there is one auxiliary variable which actually connects these 2 information.

So, this arrow here looks quite messy at least initial model it need not be. So, messy even if you are connected at one place it is fine, we are not looking at accuracy as a model yeah as long as there is an extra variable here. So, units of it will be say pieces per order that is the units. So, we can do all multiplication condition or whatever it is we want to do. So, get on the calculations, ok.

So, in this, so you want since you are practicing I can tell you this is an important link, this is an important link and this is an important link. If you are captured these three arrows in your model that sufficient, the other two's are optional. If you have figured it out, it is good, it is not you will get it by practice, do not worry about it. So, this arrow indicates that I am using this information here.

So, it is important this arrow indicates that this and this has connected. So, it is important. And this is an extra information used to connect these two, so that information also somehow used in this calculation, so that is all it says. So, after that we can the at least those three arrows are minimum required to have a decent model.

Again as I mentioned cloud clouds indicator infinite thing or infinite source that marks the boundary of your model. Whatever happens to that afterwards we do not care about it like it is already shipped that is all you worry about as long as left my premises I do not care when it reach the customer yet. If it is required, then we capture it if not that marks the boundary of your mode? No, there is extra delay that is described in the described here customer (Refer Time: 17:43) not immediately fulfilled. If you directly connect it; that means, immediately fulfilled.

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That is what I am saying as soon as order comes is not immediately fulfilled that is how the description says. There is a delay caused by order processing credits etcetera. So, there is some delay in there. So, to capture the delay, we are modeling a stock. So, while they end up doing that, so after sometime only the order is ready for shipment or maybe one week later.