Introduction to System Dynamics Modeling
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Lecture - 20.2
Supply Chain Models - II

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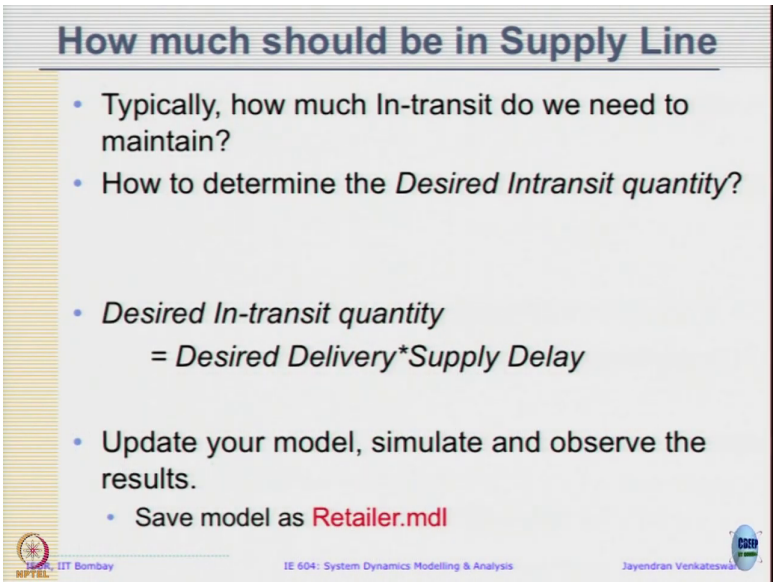

Right, typically how much in transit do we need to maintain? Typically how much in transit do you think we should maintain? Just think logically, it takes 2 days for whatever I order to come right and every day I am going to place some orders then how much should be in transit?

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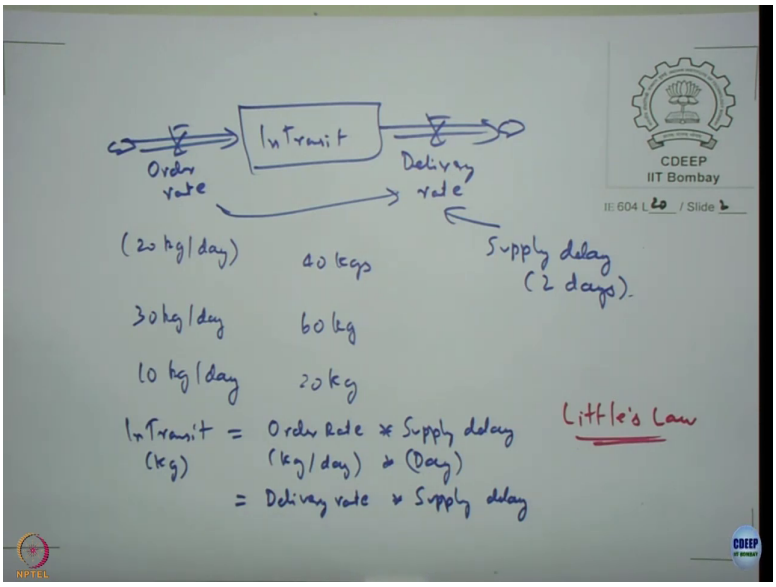

So, let us sales rate is 1 fine, there is no sales rate here. I have in transit, there is some sort of a supply delay right and I know in steady state we always operate in steady state right to determine these thing.

So, in steady state order rate equal to delivery rate, so it does not matter where I am looking into order rate or delivery rate that is fine. So, suppose I know delivery delay which in this case is 2 days right and I am ordering some quantity, let us take it has 20 kg per day, how much should be in transit in steady state? 40 units right, so, in transit should be equal to 40 kgs.

Suppose my order rate became 30 kg per day then what happens during transit? 60. Same thing, if it becomes 10 kg per day, in transit should become 20 kgs. Supply delay does not

change because after some point we expect that order rate will be equal to delivery rate, so we want it.

So, whether I am going to call it order rate or delivery rate, it remains the, it does not matter. So, this case what we are saying is in transit is equal to order rate multiplied by a supply delay. If you want to look at the units it is kg per day multiplied by day or this is same as delivery rate multiplied by supply delay.

So, this expression it is actually neatly integrates or neatly relates quantity in transit or work in progress along with your throughput rate; there is how much your sales is happening per day, what is the throughput multiplied by the flow time the total duration which is going to flow.

So, this particular relation is also known as Little's law named after John Little who formulated this work in process is equal to throughput rate or the delivery rate multiplied by the flow time that is the supply delay right here that much quantity has to be in transit. Who has seen Little's law before? You should not have asked the question how much should be in transit, you should tell it is good. So, it has to hold here also right, so model is we just write tomorrow ok.

Now in steady state I know order rate equal to delivery rate, but in reality what do I want? I want my in transit. So if actual in transit is a product of delivery delay into supply delay, my desired in transit should be product of look into your model; desired delivery delay and the supply delay, the exactly what we are going to do.

I am already adjusting my desired quantity, so, the desired in transit quantity will be equal to desired delivery multiplied with supply delay. So, because you already computed how much is the desired delivery that we want and we are adjusting our ordering policy to reach it. So, at some point in future my delivery should be equal to my desired delivery.

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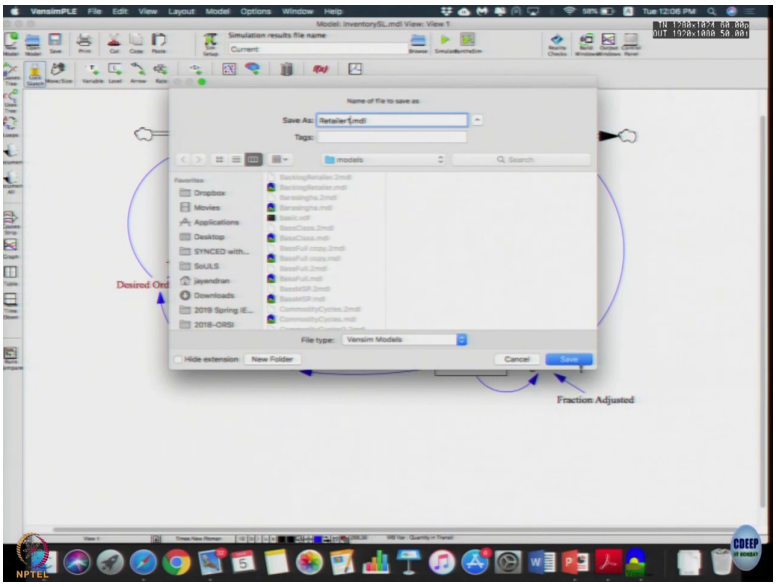

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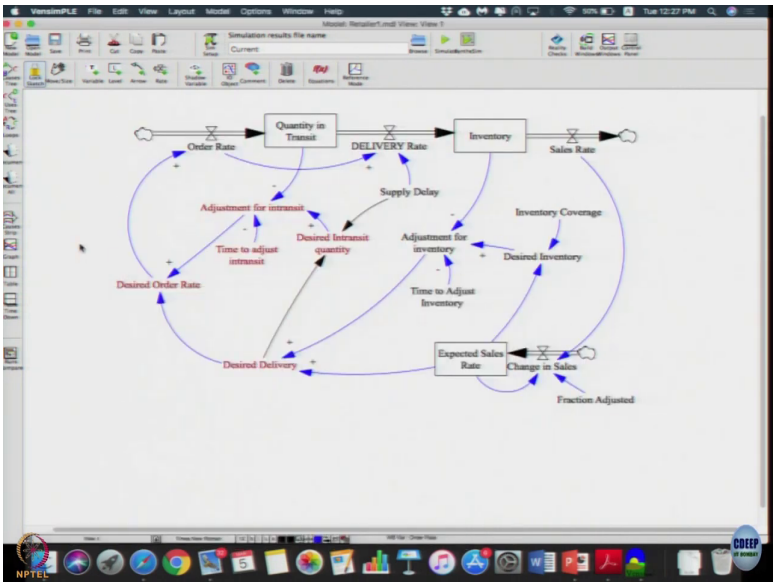

So, I am going to set a desired in transit quantity to how much I am going to desire it to be, that will give me my reference level in which I want to adjust a inventory. Why did not you incorporate this change and now save as your model as Retailer dot mdl and this model will continue for some time because the model is getting closer to more supply chain plain model rather than just a inventory model. So, let us go ahead and incorporate this. File save as Retailer, so what I am going to do is desired delivery delay and supply delay is going to linked to desired in transit.

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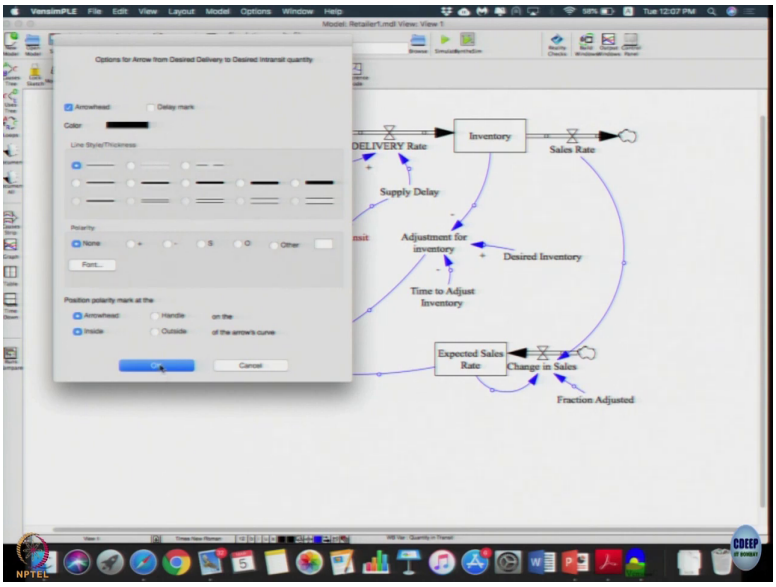

So, added these two links here. So, these were following is then and this is the black arrow to distinguish it. So, you know which arrow I blue; click equation desired quantity in transit. If you can see that desired delivery delay is kg per day, supply delay is day, they were desired in transit. Let us just make it as product of the desired delivery and supply delay. This is only change that is been made within a model.

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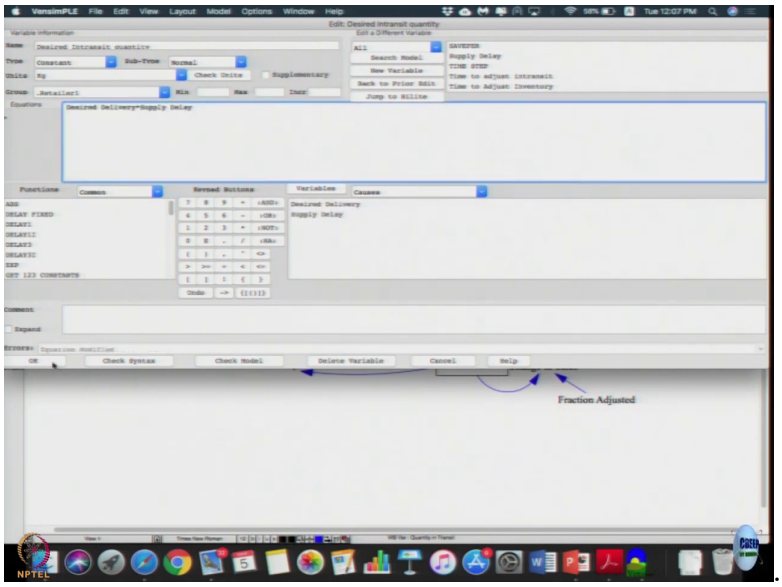

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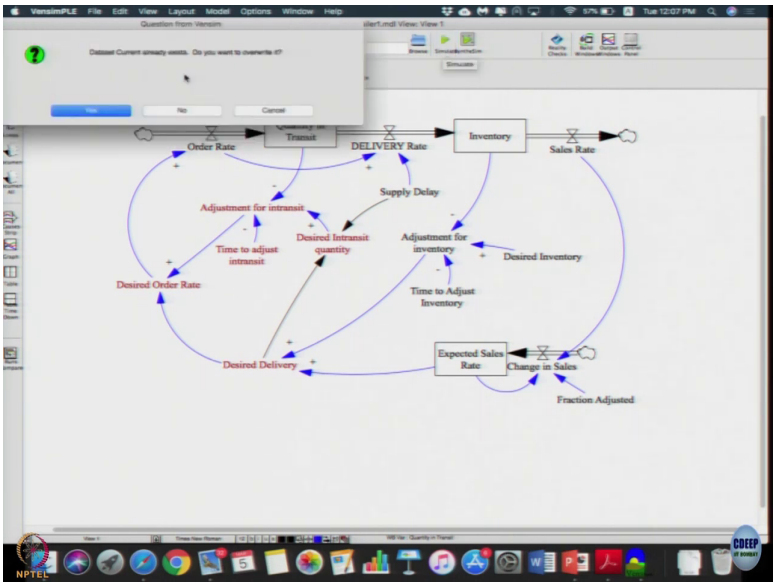

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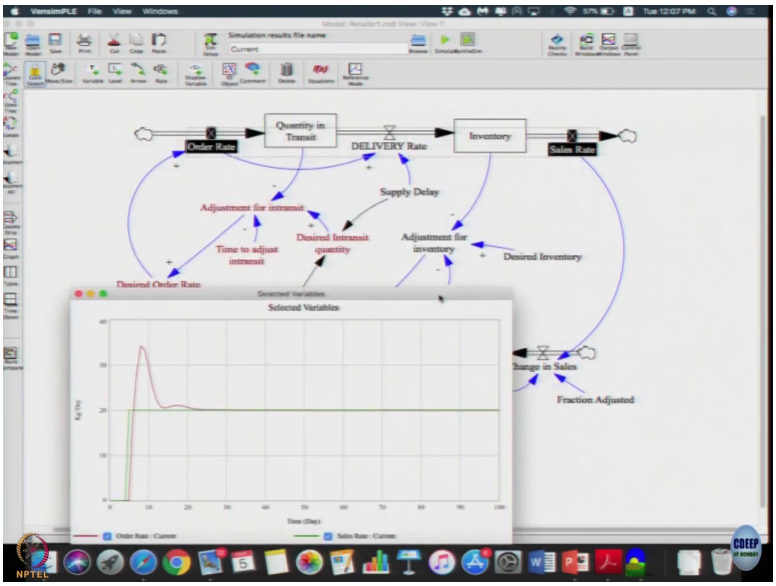

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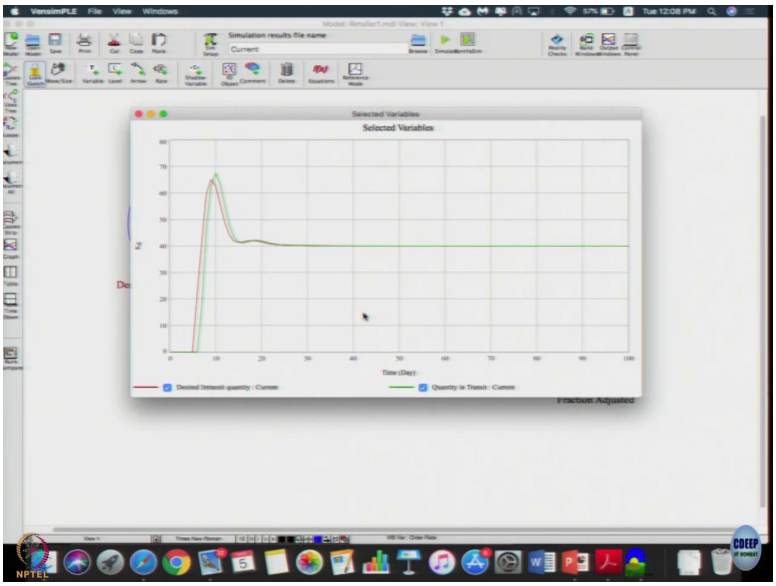

Now, let us run it. First we observe is the order rate and sales rate then it is a similar but still there seems to be one extra jump ok. Now let us observe the desired quantity in transit and quantity in transit. So, initially it was 0, quantity in transit then it rose up and saturate around 40. So, we are getting the desired value equal to the actual values then we are happy what we desired is what we achieve. What about inventory and desired inventory? Last time we found that it fell down to 160, let us see what happens now.

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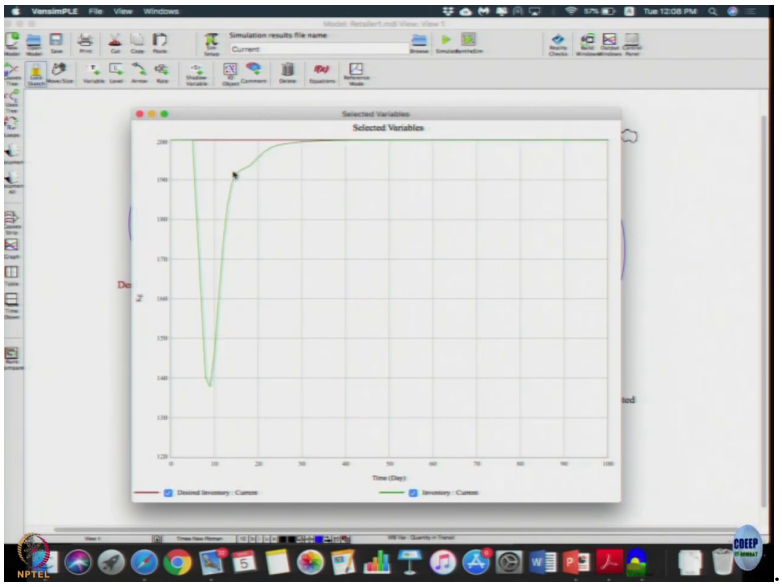

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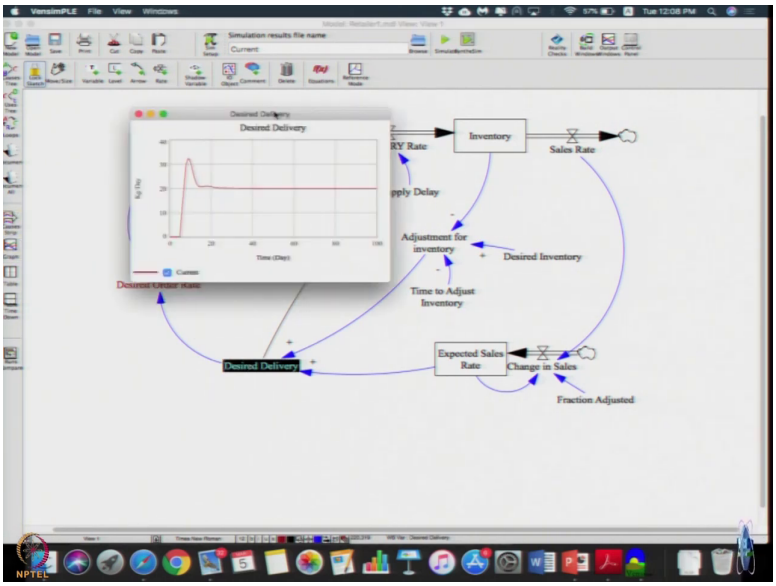

Now miraculous state is able to recover and reach back to 200, which is a desired inventory value; still there seems to be some small things linear models here. Let us look at the desired deliveries and compared it with the delivery rate itself. This; I hope you are observing what we are trying to do, like whenever I am comparing I am comparing the desired values which acts as reference with what is the actual value that we are actually seeing which is how we are going to compare and make this, whenever there is a gap that is what we want to adjust I mean resistance.

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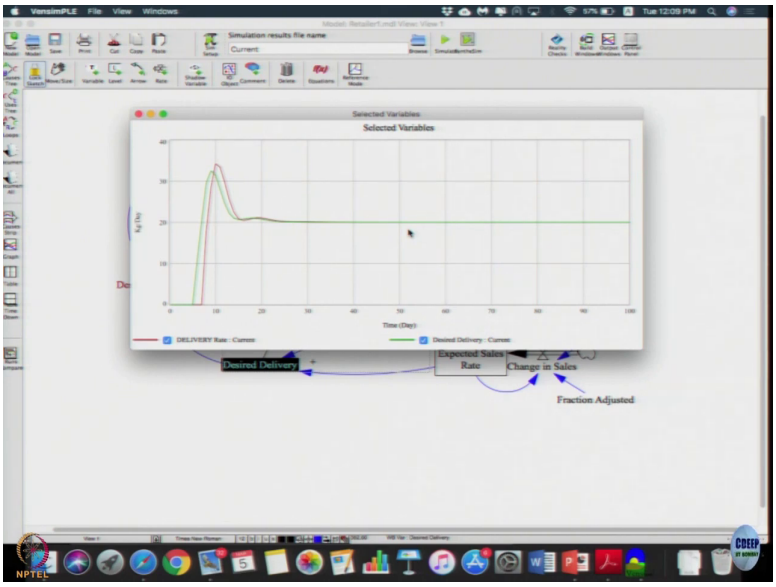

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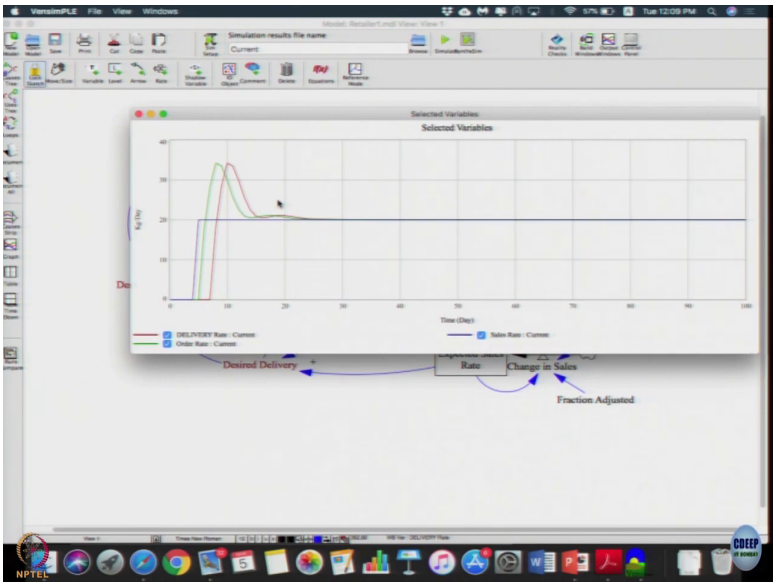

We find that even desired delivery, delivery is also saturated around 20 which in steady state that is what we want because steady state order rate has to be equal to delivery rate which has to be equal to your sales rate. If we compare all these three we can find that as the step increase in sales rate cause that order rate to first increase and delivery rate will be just off set because, we have used a fixed pipeline delay. If you have used a third order delay then you will get a kind of a smoothing action that would have happen here, but we assumed the fixed pipeline delays, whatever you have order definitely coming, so, these what the we have to write here.

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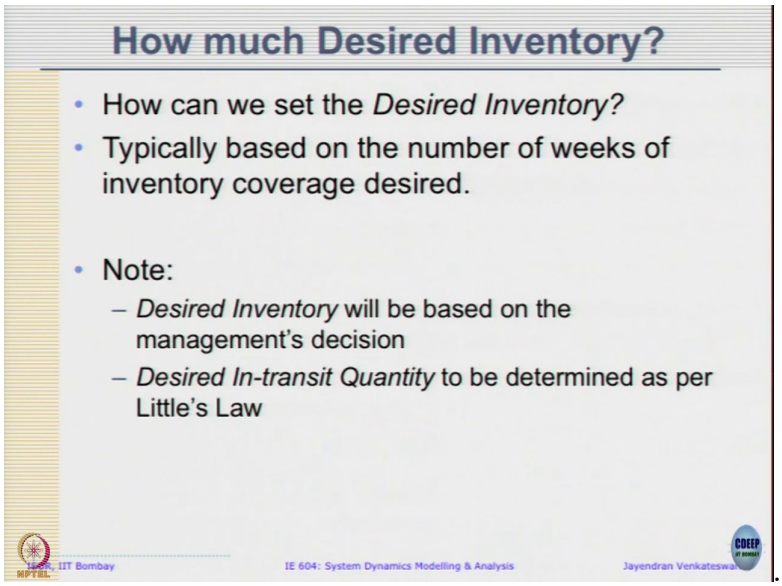

Now that we have set the desired supply line which was defined by Little's law or rather by the actual physical properties of what is expected to happen in reality. How do you determine how much should be desired inventory? Desired inventory we arbitrary set at 200 units right; 200 kgs. How do you determine the desired inventory? It is depends on sales rate and safety stock good. Basic idea here is the desired inventory is actually determined by the management and not by the physical properties that is underlying here.

We are hoping the management will able to set some policies and it depends on how much actually inventory coverage you want right. It is a good of trade off customers demanding things whether you want to have a 1 week of inventory, 2 weeks of inventory, 5 weeks of inventory to cover your, you know buffer again some uncertainties or changes in demand. So, that is what you are going to use to determine and how many weeks of inventory you want to carry as a desired inventory, how much weeks of inventory.

So, typically it is based on number of weeks of inventory coverage that is desired, not the desired inventory will based on the managements decision. So, we have to actually estimate this is the main demand this is the variance in the demand, based on that we feel that we need at least 2 to 3 weeks and there is some variance in the lead time to. Suppose then we will use it to figure out how many weeks of inventory coverage or like to keep.

So, now, inventory is no more a quantity in kg rather we are looking at how many weeks of inventory you want to keep corresponding to the demand. So, let us update our model to reflect that. I am going to change the desired inventory values here, let us introduce a new variable called as inventory coverage. What will be the units of inventory coverage? Days, their unit time unit days, let us assume we are having 4 days of inventory coverage right, let us suppose.

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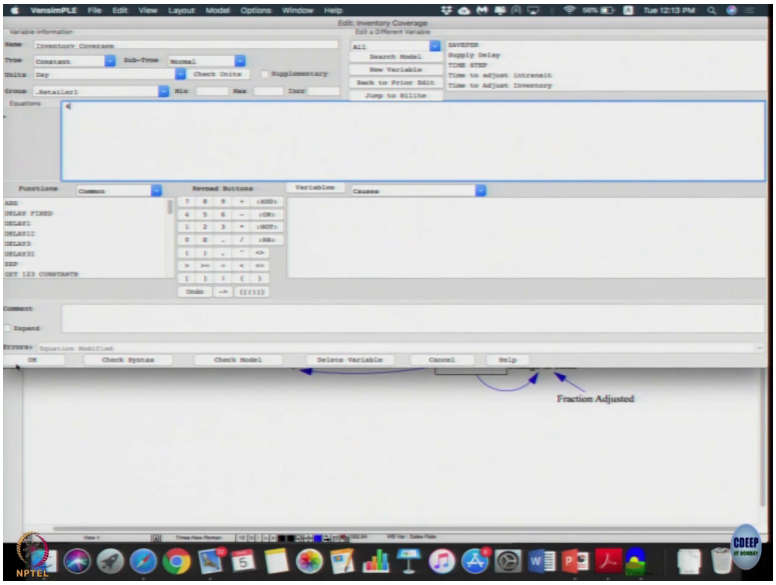

So, now, desired inventory, so how will I compute the desired inventory? The inventory coverage just told thus that we need 4 days of inventory. 4 days of what? 4 days of actually the sales rate, but sales rate is something we know only after it happen. So, we have to work with the expected sales rate; let us just include expected sales rate. I think, that inventory coverage into expected sales rate.

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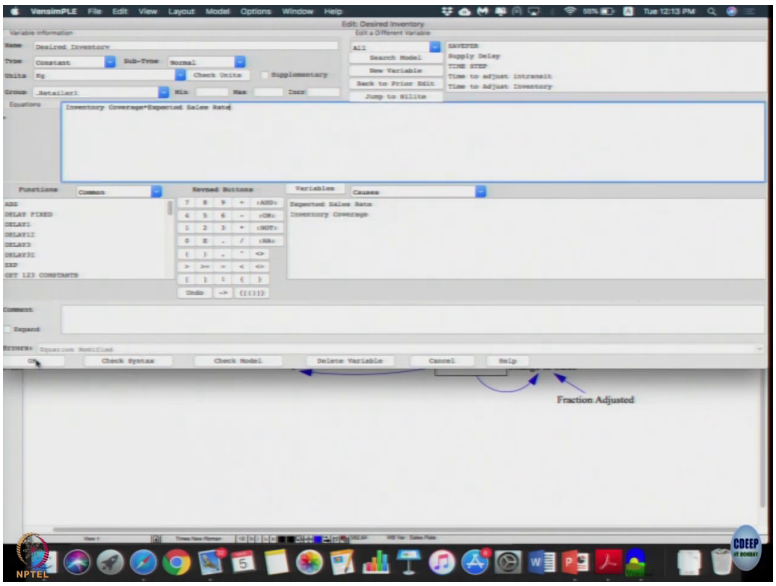

So initially expected sales is 0, see inventory coverage is 4, so desired inventory still be 0 correct. And later when sales rate become 20 expected sales rate becomes 20 and inventory coverage is 4, so, desire inventory should be equal to 80, correct and inventory should adjust to 80. Let us simulate it and see what happens.

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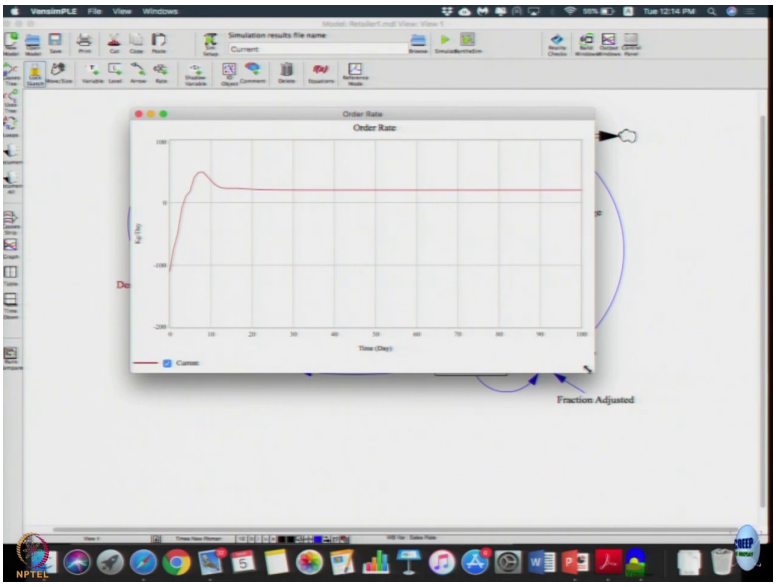

Let us look at order rate.

Student: Can I?

And of became worse, we are getting some negative orders. How do you think this is a negative order? Negative order, is there negative order initially, the previous model you would have found that the order is started at 0. Now this is a negative order why? Already there is some initial inventory right. So, how do you account for that; then what should be initial value of inventory? 0, that is why 0. I just set the initial value of inventory to 0. Order rate is fine, now it starts at 0 and goes around; let us look at inventory and desired inventory.

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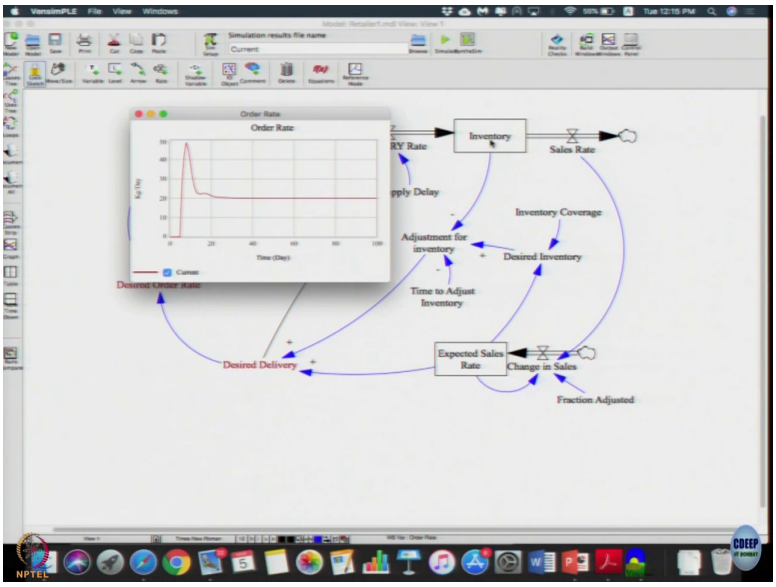

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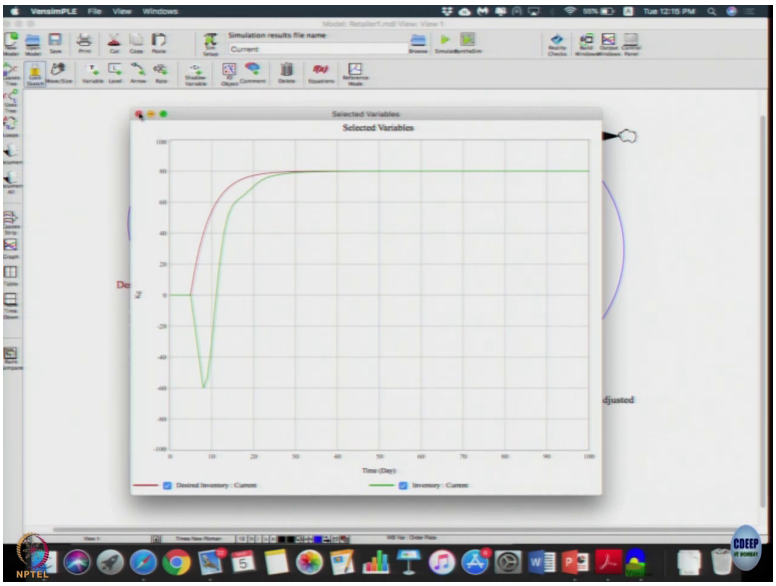

Eventually they both reach 80, so, you are able to reach a desired inventory levels and check the desired supply line that also should be the. But we also find that inventory is going negative here, it may not represent physical reality, but for now let us just leave it as it is for a minute. So, the initial dynamics we already want to model to start a dynamic equilibrium ok. So but initial value of inventory of 200; did not allow us to do so.

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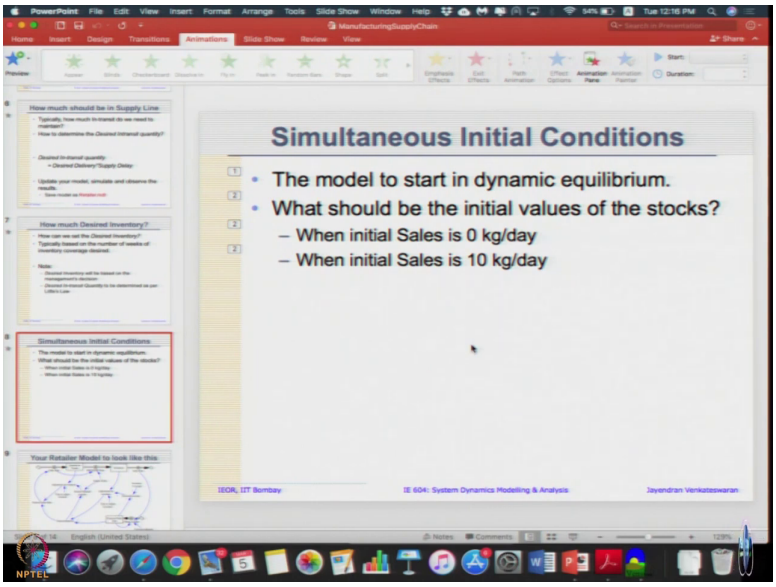

So, let us try this exercise. The model needs to start in dynamic equilibrium. What should be the initial value of the stocks when initial sales is 0? When initial sales is 0, all the stock should be 0 right ok. What if an initial sales is 10 kgs per day, what should be the initial values? You need to tell the initial values for everything, then sales rate is equal to 10 what should be the initial values? When sales rate is equal to 10, eventually the expected sales rate should also be 10 right.

So, when sales rate is 10 expected sales rate will be 10, this is fine and expected sales rate is 10 inventory coverage is 4 desired inventory is 40. And that should be equal to the initial inventory values 40 because initially I do not want any dynamics I want this model start a dynamic equilibrium. So, inventory should be 40.

So, if inventory is 40 desired inventory is 40 adjustment for inventory is 0, but expected sales rate is 10, should be desired delivery will be 10, here correct. Desired in transit will be 10 multiplied by supply delay of 2, but desired in transit should be 20, is it right? And desired in transit is 20; that means, quantity in transit also needs to be 20. So, let us try that to see whether we started dynamic equilibrium.

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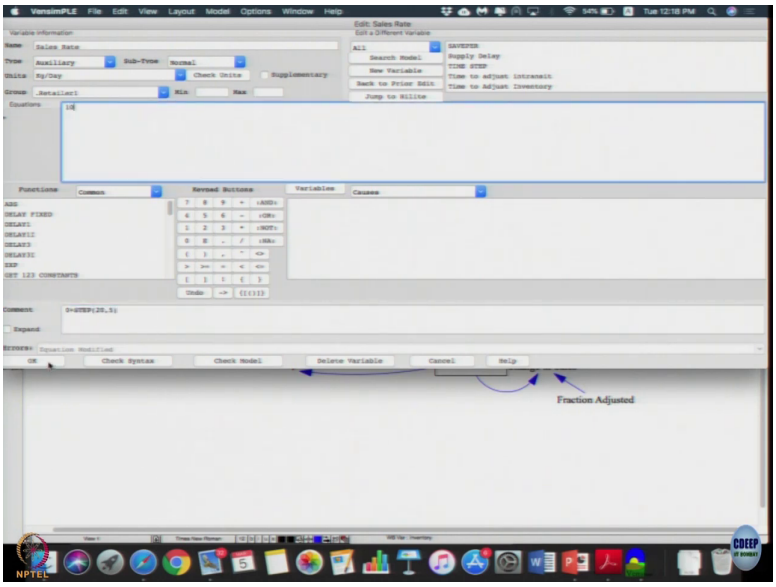

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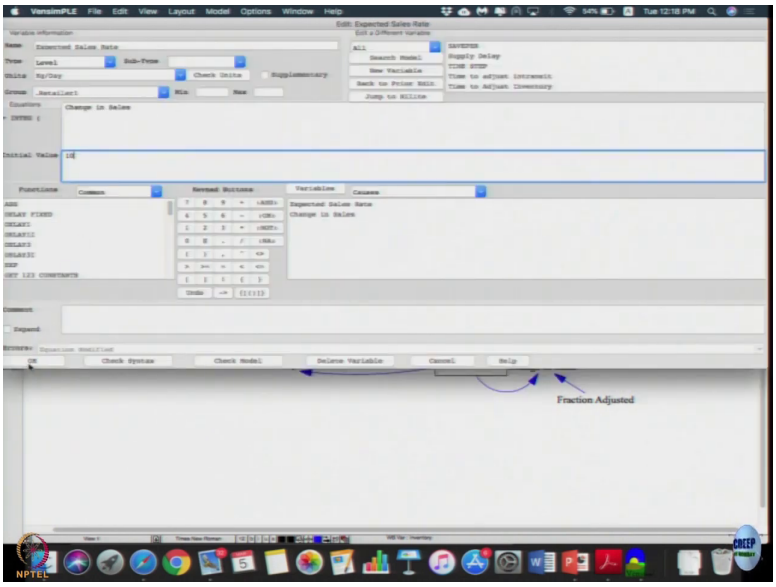

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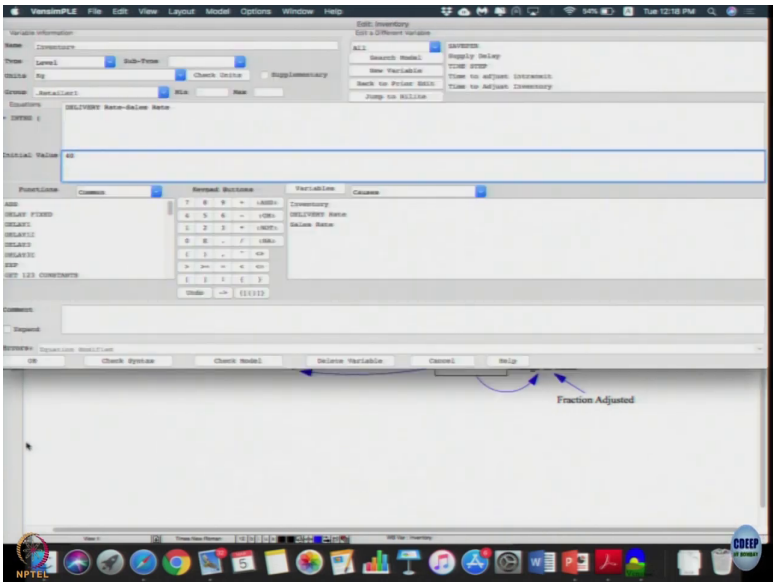

So, let us go to sales rate and just replace it with 10 just 10 kg, this makes sales rate equal to 10. My expected sales rate is 10, inventory is 40 initial value this is 20 in transit it is 20. In transit is 20, inventory is 40, sales is 10. So, when we run it model should show a flat line right.

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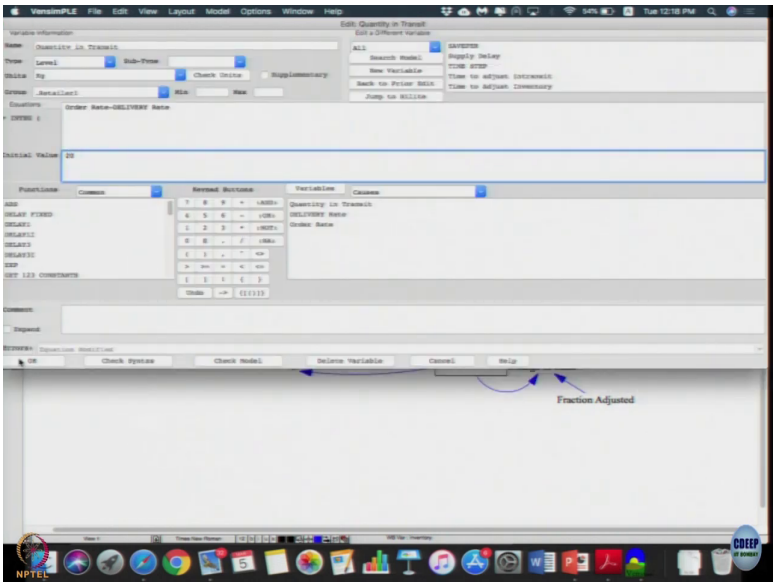

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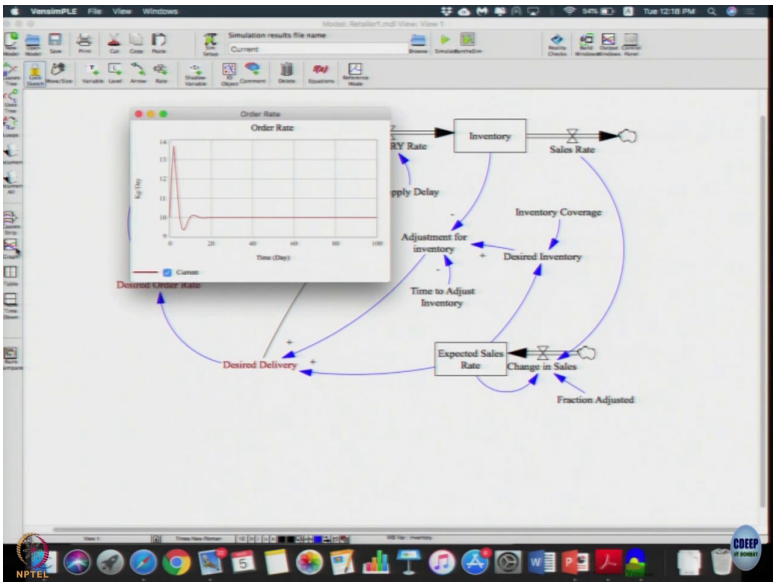

Let us see, verify it, no it does not, what did we miss? What did we miss? Carefully look at your model and tell me what we missed, what did we miss. It is important models at dynamic equilibrium. Because when we start this 1 is your time to replicate reality, but still we want the model to start the steady state.

So, then any change in future can be attributed to the changes in the exogenous variables in the model right. So, that is why you want to ensure that model starts a initial condition, this is called a simultaneous initial condition, because many variables have to take those values during steady state.

But logic we use is quite straight forward. We would desire inventory and inventory you know time 0 both are at 40. See when you observe the dynamics things started at time 0 itself. After immediately of time 0 dynamics was started, so, something is wrong with the initial condition only right we are not affected it.

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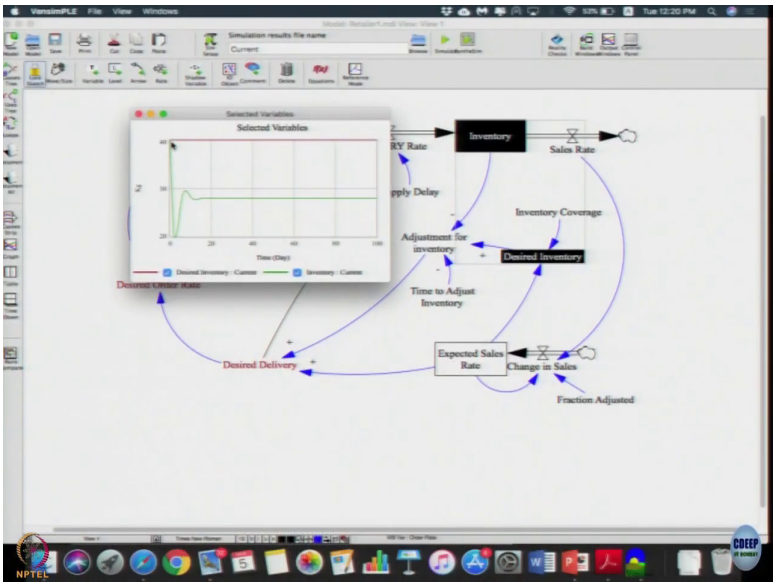

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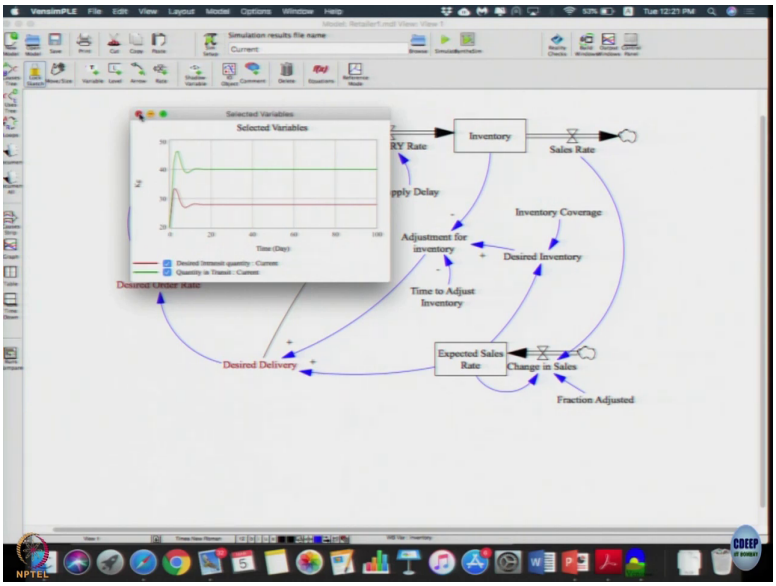

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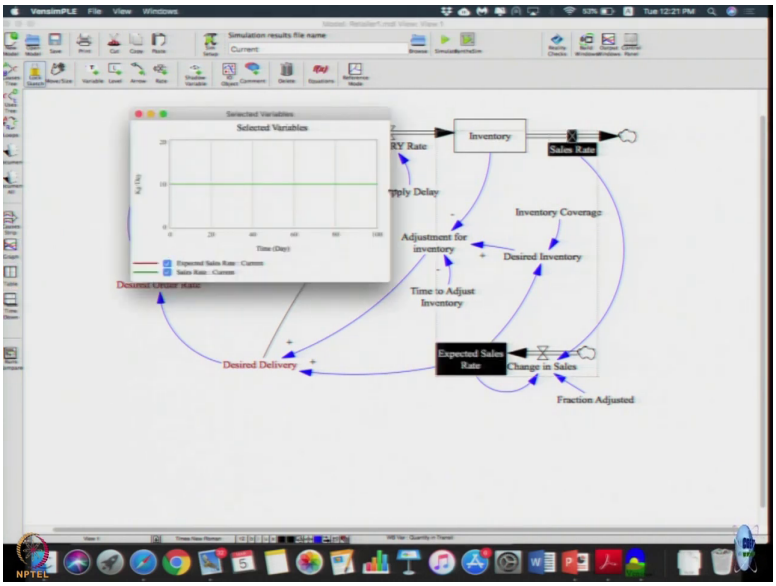

So, inventory and desired inventory now both seems to start at 40 already in transit desired quantity in transit both starts at 20. Sales and expected sales both are 10 does not change at all so even good. What else can we compare?

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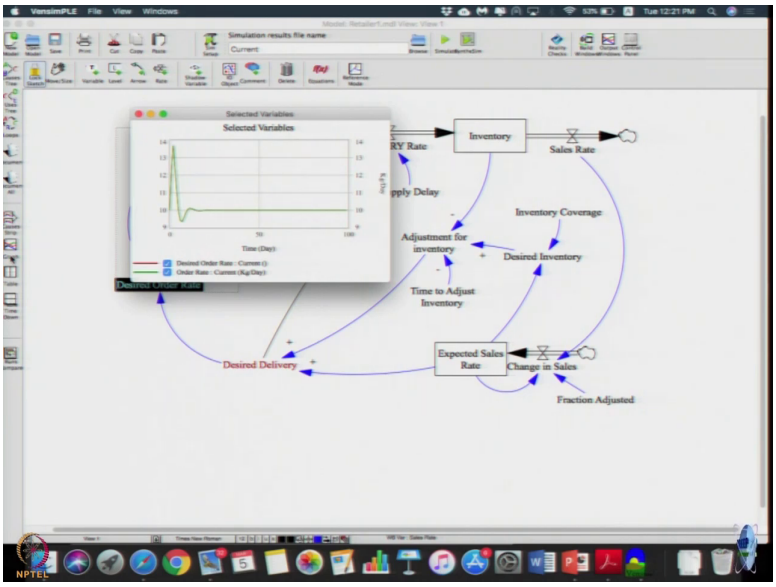

Order rate desired order rate is exactly the same there is no change in equation, desired order rate equal to desired order rate; what else? It is one more pair of things, inventory desired inventory we check yes, delivery rate and desired delivery. Let us compare them, they changed, here they are seems to start at different time different points. So, desired delivery starts at 10 which is what we want, but the actual deliveries starts at 0.

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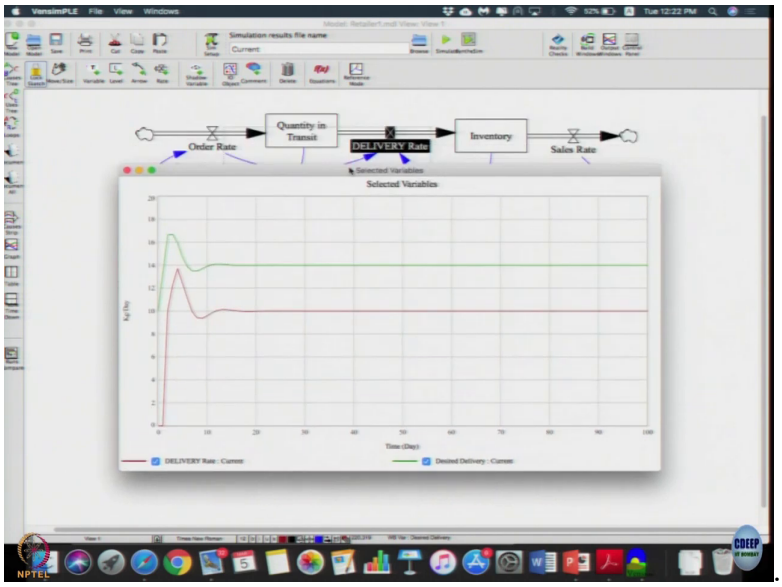

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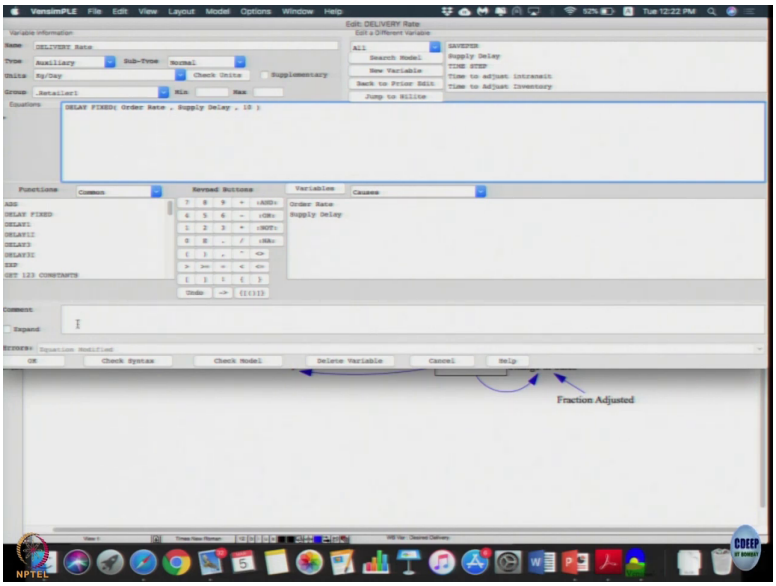

So, where did we set it to start 0, where did we set it? So, this only delivery starting at 0, it should have started at 10. So; that means, you should look at the equation of delivery rate and delay fixed order rate supply delay at comma 0. 0 is nothing but the initial value which is getting delivered, so, that should also be 10. So, this is what happens when you start putting constant inside equations. So, but we will continue to do the same mistake.

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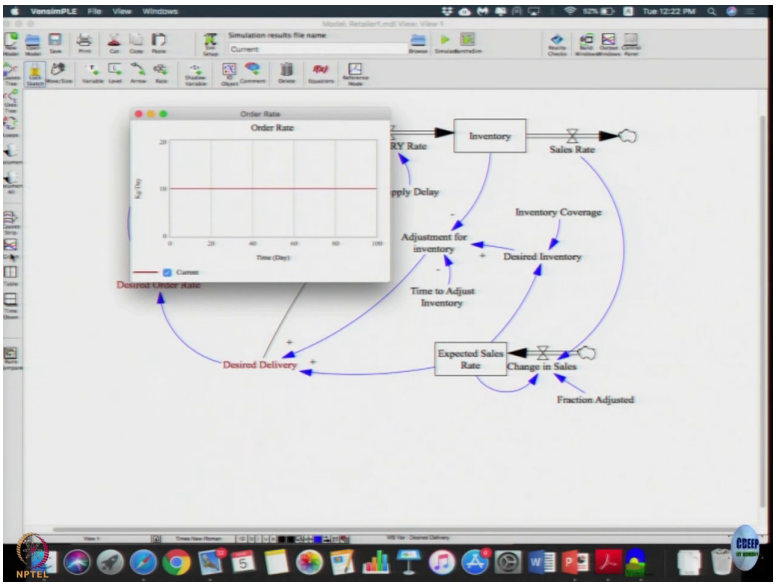

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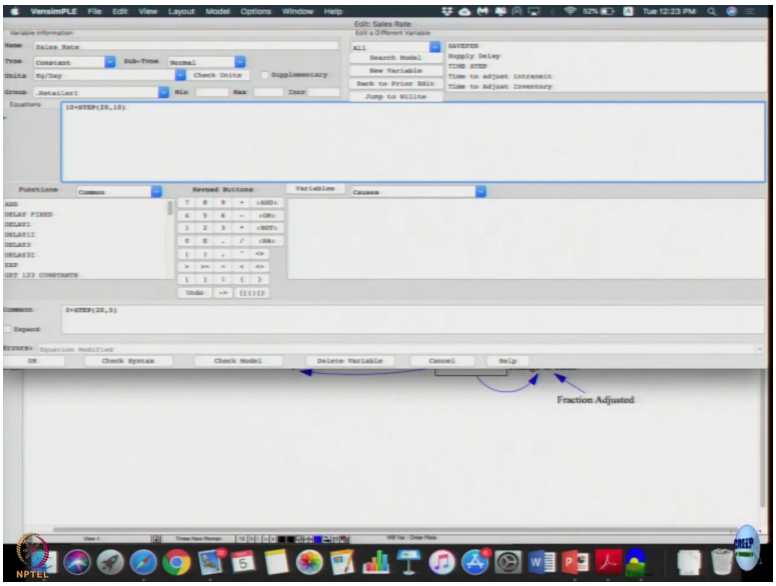

Now let us simulate hopefully there is no change in your yeah, order rate is perfectly flat. So, things are called at dynamic equilibrium. Let us go to sales rate and say we will give 10 plus step of 20th time 10. Come, I will. So, it is 10 initially at time 10 again it increases by 20, so, it will goes up to 30. Let us simulates.

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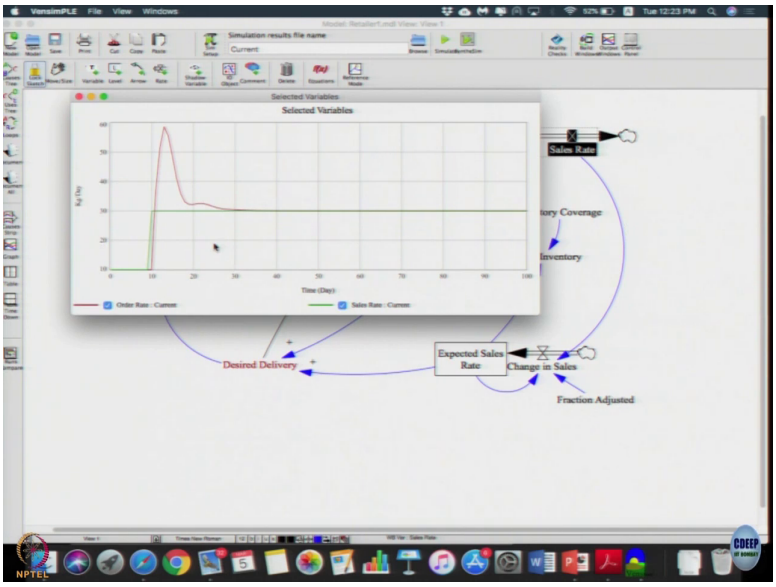

Let us compare order rate and sales rate. We get a dynamic graph as shown here. Now things seems to be ok in that steady state and all the dynamic changes that we are seeing is a result of hours changing the sales rate only and because of a pressure structure.

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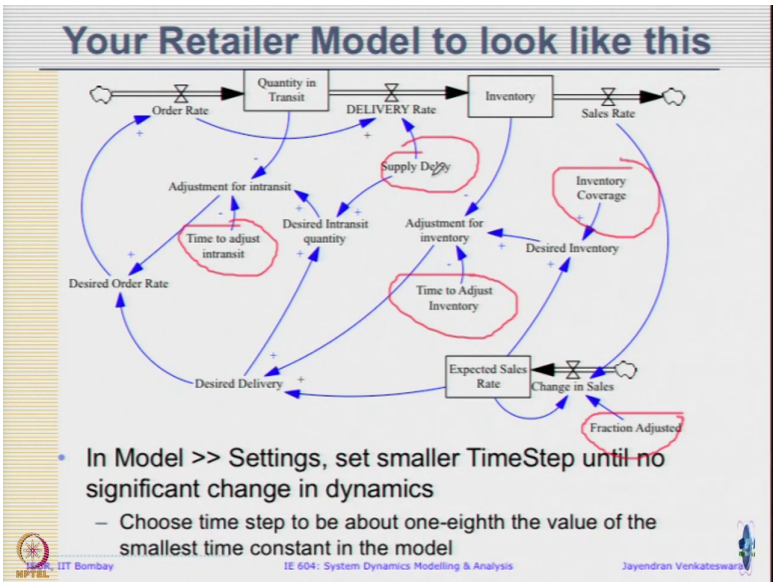

So, this way the model should look like, it is what we have been looking at. In models settings sets smaller time step until no significant change in dynamics occur. Choose time step to be about one eighth the value of the smallest time constant in the model. You have to understand that what we are actually doing is coming up setting your differential equations and using Euler method to do the integration. And Euler method is the fixed time step model, suppose Runge Kutta method.

So, and we have taken a time step of 1, so, but based on the sub delivery delays we need to keep updating it. Suppose supply delay was for say 2.5 weeks and your time step was 1; that means, you are going to clearly miss a 2.5 delivery delay time. Is going to do the time 1, time 2, then time 3; at time 2.5 it should have arrived, but it did not come. So, it will effectively capture that we need to have a small time steps of integration. The thumb rule is to have one

eighth the value of the smallest time constant. So, what are all the time constants in our model?

So, what are all the time constants in our model? This is the time constant inventory coverage, supply delay, time to adjust inventory, time to adjust in transit as well as even this fraction adjusted. Fraction adjusted that is going 1 over time. So, fraction adjusted is 0.2 so, that is 1 time constant is 5, no problem that is 5, inventory coverage was 4, time to adjust inventory is 3, in transit 3, supply delay 2, smallest time constant is 2. So, let us check one eighth of it, so we can set a time step of 0.25.

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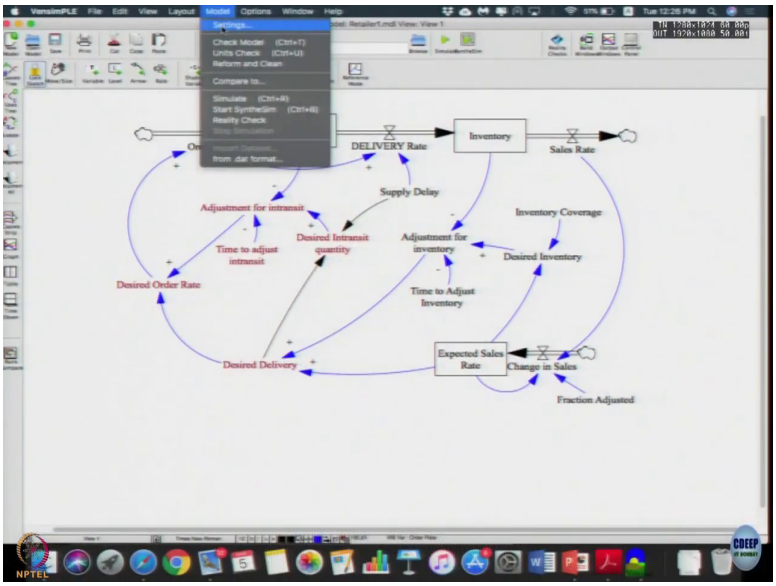

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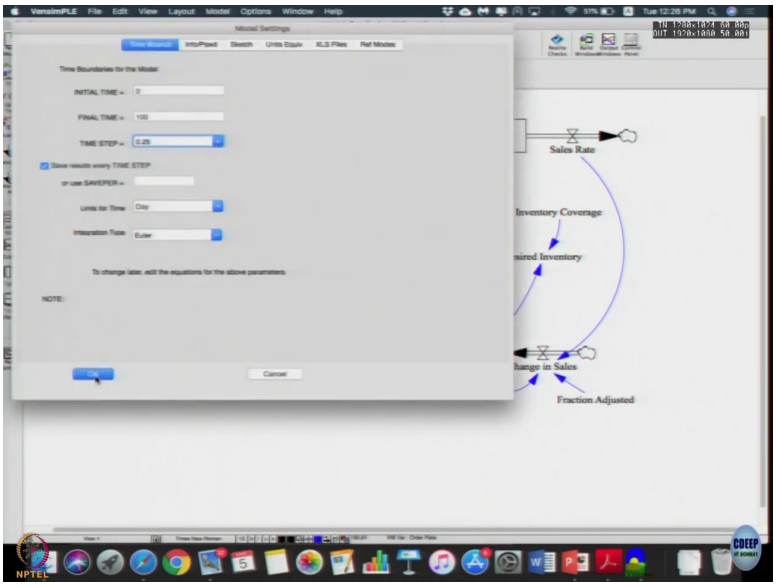

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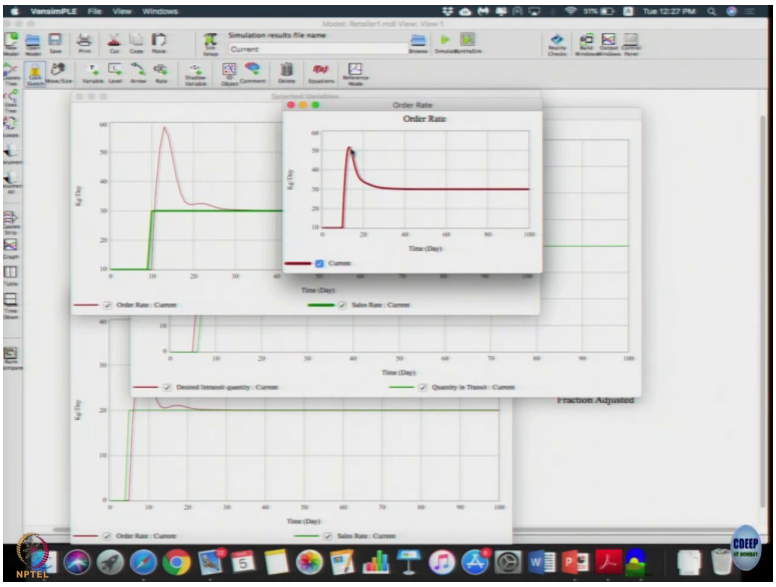

Let us go back to our Vensim model. Settings 0.25, just simulating it and let us look at order rate graph. Now you get a much smoother graph as opposed to the previous one that is because you now have multiple points at every 0.25; so it looks like a smooth graph. In the previous one it had it seems to have lot of sharp edges then compare it right here; this is the order rate previously your time step of 1, it is order rate with the time step of 0.25. Here it peaks at around 50, here it seems to peak at nearly 59 that here it is about 51.

So this is more at true representation of what is actually happening this is because of integration time step error. So, you can keep reducing it until this does not change, so one eighth is a good thumb rule to keep. So, if your delay falls down to suppose you have another delay say inventory coverage became only 1 week instead of 4 weeks, then good idea to reduce your simulation time step little more to ensure you get the correct results.

In some if time step is really large you can even see different dynamics in a model which is not that true dynamics of the system; you may see lot of oscillations or you may see exponential growth. Because of integration time step error rather than the properties of the model per sake ok. So, you can note down the integration time step. You set it at 0.25, fine, we had may not moved to the supply chain yet, we are still with the retailer. So, you need to do few more things.