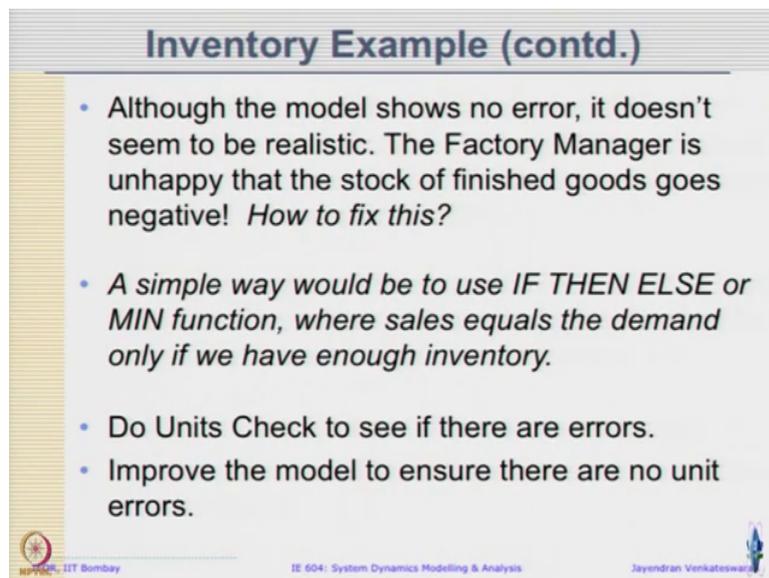


**Introduction to Systems Dynamics Modeling**  
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**Lecture - 17.2**  
**Modeling Non-Linear Relations**  
**Modeling Non-Linear Relations: Table or Lookup Function**

If you have looked at Vensim that functions help when you open the screen on the left side bottom, there are lot of functions. We have seen a few of them.

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**Inventory Example (contd.)**

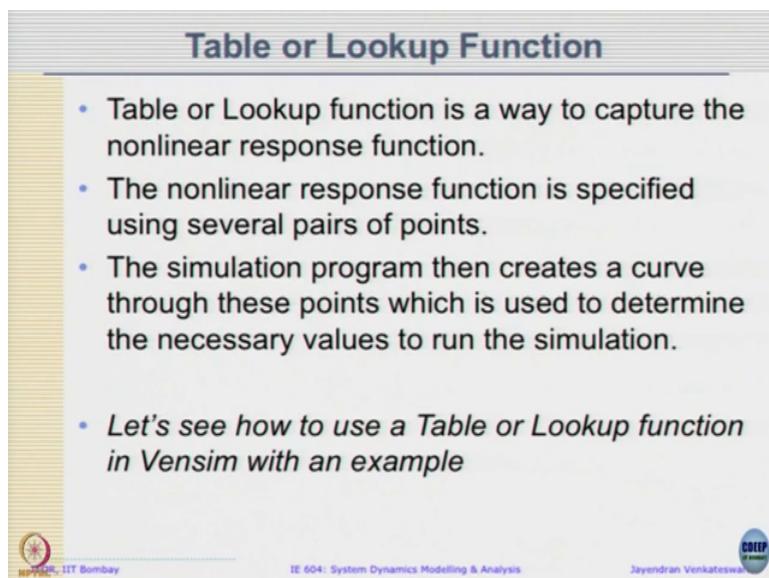
- Although the model shows no error, it doesn't seem to be realistic. The Factory Manager is unhappy that the stock of finished goods goes negative! *How to fix this?*
- *A simple way would be to use IF THEN ELSE or MIN function, where sales equals the demand only if we have enough inventory.*
- Do Units Check to see if there are errors.
- Improve the model to ensure there are no unit errors.

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Pulse, step, random normal, IF THEN ELSE, MIN possibly is the MAX there are so many other functions which if situation demands it just go over those lists and see whichever is applicable we can use it in our model.

There is one other way in which this kind of a non-linear functions are captured within our model. One is of course, if you know the analytical expression you can always put it  $y$  equal to whatever  $x$  power  $z$  or something, then we can directly capture it within the model. But many times such an analytical expression may not be available for us. So, in those cases either we use MIN MAX kind of function or we use what is called as the Table or the Lookup function

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**Table or Lookup Function**

- Table or Lookup function is a way to capture the nonlinear response function.
- The nonlinear response function is specified using several pairs of points.
- The simulation program then creates a curve through these points which is used to determine the necessary values to run the simulation.
- *Let's see how to use a Table or Lookup function in Vensim with an example*

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So, for second example, we will study how to model table or lookup function. Table lookup functions is to capture the non-linear response function. We do not know the analytical expression, but we can somehow guess the shape of the function and we are going to include it graphically or using several points or several pair of points are going to be given.

So, basically what we are going to do is give several set of points for inputs and outputs of the variable and when simulation model runs, it is going to extrapolate or interpolate between those variables and give me the output response as simple as that. So, if I know the shape of the function, then I am going to feed those pair of points into model and it is going to interpolate or extrapolate. So, simulation model then creates a curve through this point which is used to determine necessary values to run the simulation.

So, today's class, we will learn how to implement this Table or Lookup function in Vensim with different example. So, we will get familiar and how to input it, for this we will a take up a non inventory kind of an example.

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**Rat Population Growth Model**

An experiment had been conducted on a population of rats. The rats were kept in controlled environment of area 11000 sq. ft. with sufficient food and water supplies. Soon, the population began to thrive. New rats were born. Old ones died after an average lifetime of 22 months. No migration or predation of population was allowed. The experiment found that population density affected infant mortality, which reduced the birth rate, while the death rate remained unaffected. Initial rat population was 10. Assume age doesn't matter for reproduction and the male:female ratio is 1:1. Also, the normal rate fertility is 0.4 rats/ female/ month.

**Build & simulate a SFD of the above scenario**

Controlled experiment on population of Norway rats found that population density affected infant mortality, which reduced the birth rate (Based on Calhoun (1962)/ Goodman (1989))

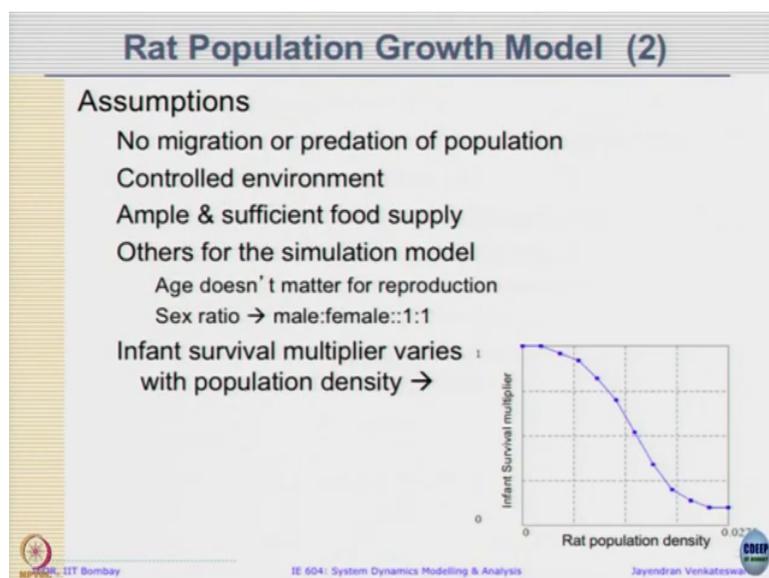
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We will move into this rat population growth model, the fair bit of text bear with me and just through it. An experiment has been conducted on population of rats. The rats are kept in a

controlled environment of area 11000 square feet with sufficient food and water supplies. Soon, the population began to thrive. New rats were born. Old ones died after an average lifetime of 22 months. No migration or predation of population was allowed.

Experiment found that population density affected infant mortality, which reduced the birth rate, but the death rate remained unaffected. Initial rat population was 10. Assume age does not matter for reproduction male female ratio is 1:1. Also normal rat fertility is 0.4 rats per female per month. We need to build a stock flow diagram of the model. This is actually based on a paper.

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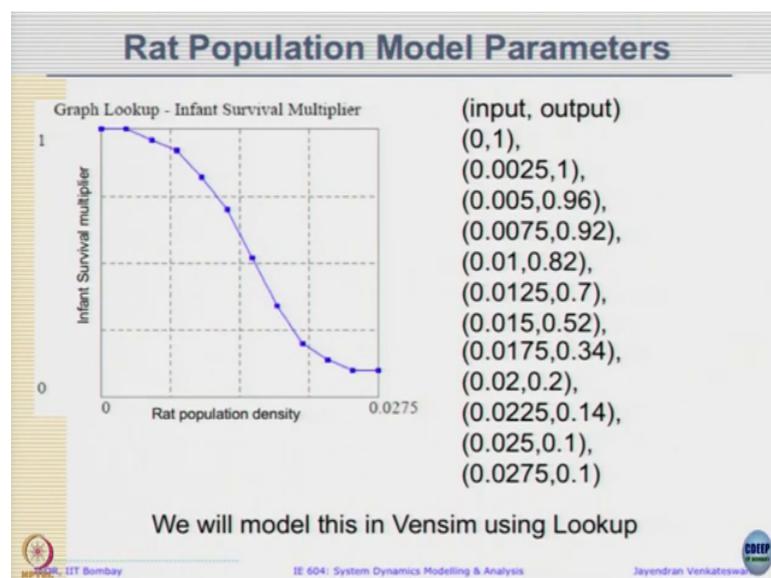


So, there are some assumptions given. No migration which we just saw is controlled environment ample and sufficient food supply. And the infant survival multiplier, let us say how the infants sup survival affects is affected by the population density, that let us assume it

is given by this curve right here. Rat population density is in the x axis and that gives us an output of infant survival multiplier according to this particular curve right here. We do not know the analytical expression for that; we just know this curve. So, what we are going to learn is how to input this curve directly in a Vensim model is what we are going to see.

So, as density is large, the survival multiplier goes down; if density is low, then everything survives because on the top most y axis it is 1 ok. So, there is dots you see on the lines are the actual points. So, when I simulate if a density is between any two points is going to interpolate; if it is outside the range, it is going to extrapolate the last two points ok.

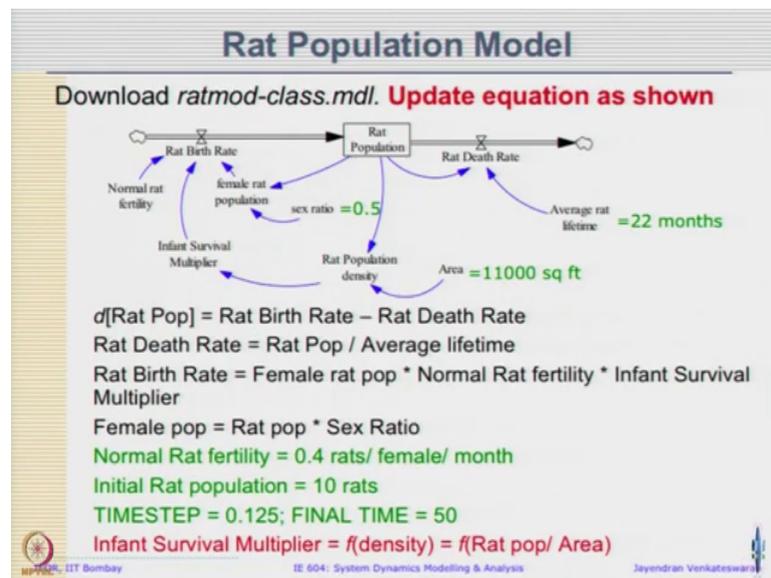
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I hope everyone knows how to interpolate and extrapolate. Good thing is you do not need to do it, Vensim will do it. We have zoomed in view of the same graph along with all the numbers of inputs and outputs ok. We will model this in Vensim using what is called as the

Lookup function. So, but this is just one parameter which is in the entire model. We have the remaining set of model which anyway you have to model to make our lives easy.

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Partial model of it is already available, please download it. So, already downloaded it, open it. This is the entire equations underlying it, but the model if which you have downloaded will not have any equations in it. Please write the equation as per what is shown here

Again here the stock is shown as a d of rat pop. We are differentiating it based on birth rate and death rate. So, the stock here is represented in this format. Using this equation and the constant parameters are also given. You may go ahead and write the equation except for the last one infant survival multiplier which is a function of the density. Density is nothing but population divided by area. Do not write anything, do not need to open it because I have not shown you how to enter a table function. So, you finish all the other equations. You no need

to do the equation of infant survival multiplier, but for all the other variables ensure equations are given written or the constant value is mentioned.

The initial rat population is 10; the initial rat population is 10 that is also mentioned. So, first before we go into that let us just quickly look observe the model so that we can get a feel of the kind of behavior, how a population affect that birth and death rate very simple model. So, either we need to get an exponential growth or we are going to get a exponential decay; however, there seems to be some population density affecting it. So, we are going to get expect what kind of behavior as a carrying capacity of the system affects my birth rate ok.

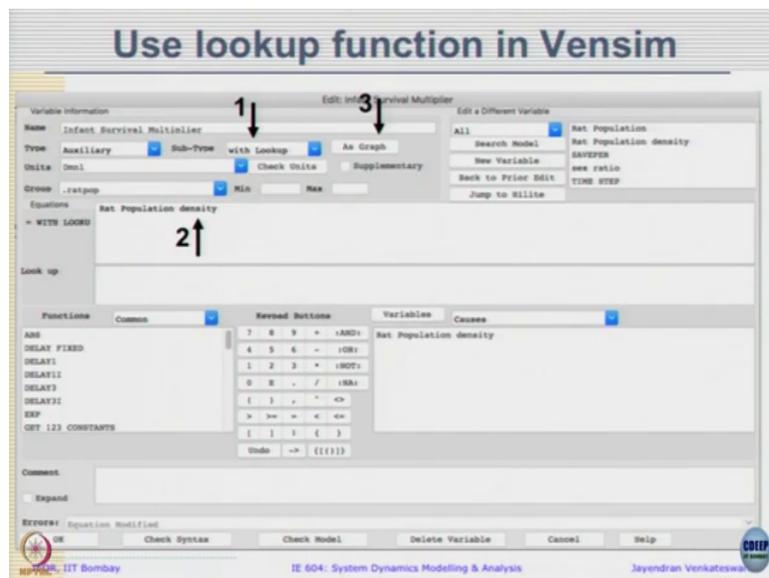
Let us assume infant survival multiplier is 1 initially ok. So, if you look at the equation birth rate will be rat population into sex ratio which is 0.5 multiplied by rat fertility which is 0.4. So, and the rat population is 10. So, 10 into 0.5 into 0.4 and on that right side, we have death rate which is 22 months which is greater 10 by 22 or 10 into 0.5 into 0.4. So, birth rate is more than death rate right. Assuming infant multiplier is 1; anything complicated, we just what we do analytically we assume it is 1 and get rid off the multiplication effect which is there infant survival multiplier is 1. So, its affect is may redundant So, birth rate is more than death rate. So, we need to get exponential growth correct.

The previous slide we were seeing that as the density becomes larger, by a multi infant survival multiplier is going go down to up to 0.1 from 1 it is going to 0.1. So, the same model if I multiply it by 0.1 at the extreme so; that means, my death rate at that point is going to exceed my birth rate. Once death rate exceeds birth rate, then I am going to get a exponential or goal seeking behavior.

So, what is the final behavior? It has to be s shaped initially, we just say if it is one I am going to get exponential growth, but later final stage it is going to get death rate is more than birth rate, goal seeking behavior. So that it means it has to be an s shaped behavior right. So, why I am saying that is important because if you have to construct this infant survival multiplier, that is what we will do. Initial infant survival multiplier will be large because birth rate is larger than death rate and initially there is no restriction. So, it can keep changing.

Later when the density is going to reduce my birth rate that are indicated, by increasing the infants or reducing the infant survival multiplier from 1 to a very small number. Logically if it becomes 0, then death rate is very high. It has to come close to 0 or whatever is the value. So, this is how we will argue to figure out what kind of shapes we can get and think about it; not many other shapes are possible in case of such how density affects it not many other cases are possible. Because we have first the values are 1 up to the density up to some point it will be 1, then below with some density it will be some small value. So, how many shapes of line can we draw connecting these two points? Not many ok. So, that is the logic it is going to work.

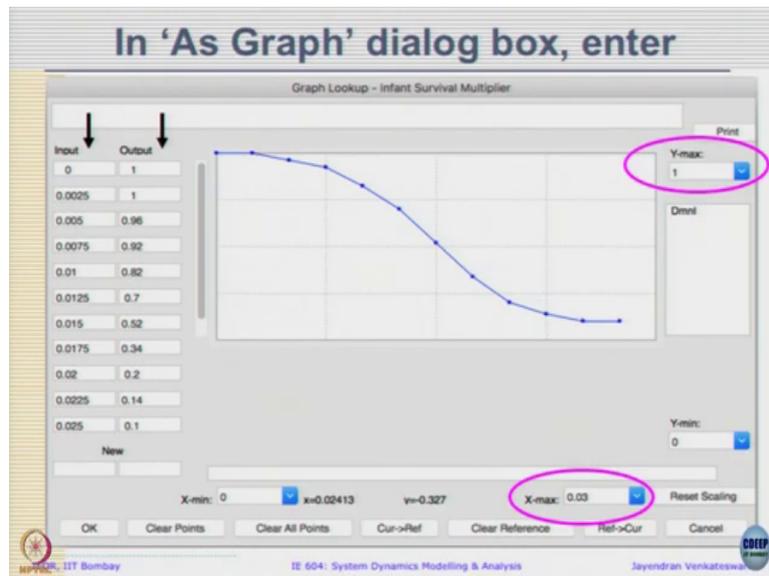
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So, to input it open the infant survival multiplier dialogue box and do step 1 first, then step 2, then step 3. In step 1, you have to change the dropdown to say with lookup and in step 2

ensure rat population density is inside that with lookup and then 3 click as graph, you got the next dialogue box ok.

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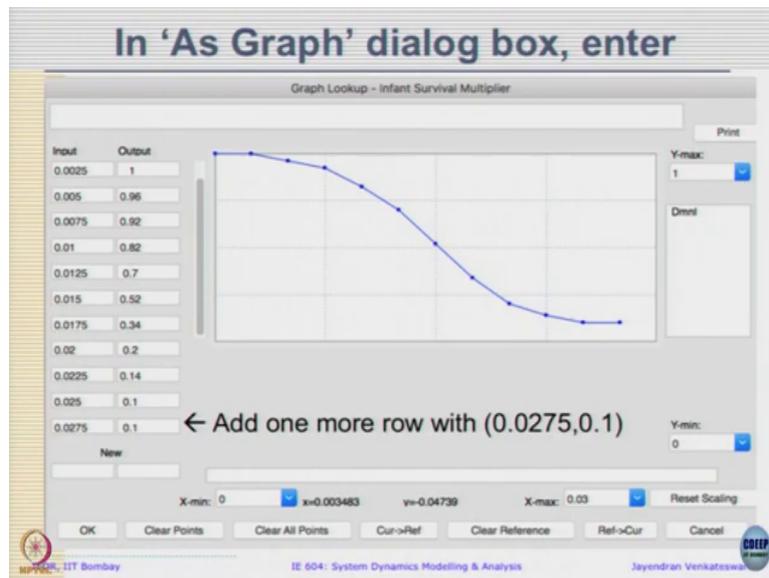


Next dialogue box you need to enter the numbers. The input output combination we gave in a few slides earlier I have just replicated it here or reproduced it here. So, you just manually type it 0, then write output 1. Enter this input and output. What I shown in pink circle, you can set that Y-max and X-max so that you can start saying the graph similar to that.

The x axis goes in the increment of 0.0025, 0.005, 0.0075, 0.1 it goes in an increment of 0.0025 is increment size in x axis, y axis goes kind of non-linear you have to see here.

After you finish do not click ok. Just keep the screen open, do not click ok.

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I am sure you have written the few values. However as you go down you have to add, there will be two entries with 0.1. So, starting there are two entries with 1. As you go bottom, there will be two entries at 0.1 on the y axis. I just scrolled it. If you go look at the scroll bar here is starting with 0 here, but it goes only to 0.025. Actually it goes up to 0.0275. The scroll bar went down. To add one more point, you have to just use this new area. Any reason why we are doing that? Why we have two values at the end with 0.1?

So, that if x axis that is the population density grows more than that still my infant survival multiplier will be 0.1 else will interpolate extrapolate the last two values and will further decrease. If you do not want it, then you need to ensure that it extrapolates correctly. So, you got this finished it, then you can click and click simulate and see the results. Those are simulating; however, we get a s shaped curve, observe the inflection point, what is the point of saturation of the population, from 10 where does it saturate, what kind of behavior's that

occur. You can observe that you can observe how birth rate changes, you can observe how death rate changes.

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**Rat population model simulation**

Simulate *rat pop model* with initial population= 10  
When does population reach stability?  
What is the stable population size?  
When is the 'inflection point' ?

What if..

- Initial population = 0 rats
- Initial population = 150 rats
- Initial population = 250 rats

What behavior pattern do you observe?  
When does population reach stability?  
What is the stable population size?  
When is the 'inflection point' ?

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You can observe this, when does population reach stability, what is stable size, When is the inflection point.

We can try a few what if scenarios also. What if initial rat population is 0, then we don't expect any dynamics right; we just multiplied by 0 so, no dynamics occur. What if initial population 150 rats or 250 rats? What kind of dynamics occurred? Do we still get s shaped? Just check for 150 and 250 rats population to see whether we will always s shaped or it is beyond inflection point. And stable population the same in all the cases or is it different? The stable population affected with initial population you can simulate in. So, what we have seen

is another way to simulate s shaped growth. We had seen a few ways to simulate s shaped growth.

So, in this case in s shaped casual link there is a net rate affecting my stock, but then the stock affects that on the carrying capacity in turn influence the net birth rate. It is because of the negative feedback loop which becomes the dominant loop and net birth rate goes down. So, here we have captured how that relation is affecting the net birth rate in a non-linear fashion. Explicitly the non-linear function is shown explicitly.

In the examples that we studied, I think we had a simple relation for the population where it just went from to 1 to 0 to just simulate it. The shape of the curve is quite similar except it is more realistic now where it goes from 1 to 0.1 in a non-linear fashion ok.

So, this is how we build various kind of non linearity's within a simulation model including capturing stable function. Many times we will find it quite useful because the relationship between the many variables may not be explicit, like if I want to model the effect of work load on the amount of hours worked on the fatigue. Those kind of scenarios I might actually need to think logically and come up with a non-linear kind of a graph based function instead of a analytical expression. So, in those cases, these kind of models are quite useful. So let me stop here.

Thank you.