

Massachusetts Institute of Technology Sloan School of Management

Understanding Epidemics Using VensimPLE

For use with VensimPLE, version 6.1

Originally developed by Nelson Repenning, MIT Sloan School of Management System Dynamics Group. Revised by John Sterman (MIT), Hazhir Rahmandad (Virginia Tech and MIT). Last revision: August 2013 Nelson Repenning (MIT)

I. Getting Started

This tutorial familiarizes you with building and analyzing system dynamics models using the VensimPLE software. To do so you are going to build a simple model that captures the dynamics of an infectious disease like SARS.

Background: SARS, a corona-virus, emerged in Asia in 2003. To focus our modeling effort, we will build a model to capture the course of the epidemic in Taiwan. The graphs below show the incidence (rate at which new cases were reported, measured in people/day) and cumulative prevalence (cumulative number of cases reported, measured in people) for SARS in Taiwan.



To begin you need to get VensimPLE ready for modeling. The latest version of VensimPLE is available for free download from http://www.vensim.com. When you first open VensimPLE, the screen should look like this:

Vensim:Unnamed Var:FINAL TIME	- 0 -	x
File Edit View Layout Model Options Windows Help		
Image: Simulation results file name	d Output Co aws Windows F	Lontrol Panel
Apple Image: Second State Apple Image: Second State Apple Image: Second State Apple Image: Second State Causes Lock Move/Size Variable Box Arrow Rate Stadow Variable Stadow Variable Dollgiett Comment Delete Equations Reference Mode Delete Lock Mode Mode Mode Node Node		
C E Uses Tree		*
Causes Strip		illi.
Graph		
Table		
Table Time		
Runs		
		-
View 1 III III	•	-

To start working on a new model go to the **File** menu and select **New Model...**. You'll see a dialog box asking for **Model Settings**. You'll be choosing the time horizon of your model (when your simulation will start and finish), the appropriate time step (how accurately you wish to simulate your model), and your units of time.

Vensim:Unnamed	Var:FINAL TIME	
File Edit View La	yout Model Options Windows Help	Reality Checks Windows Windows Panel
Noce Voen Save Noce Voen Save Noce Voen Save Causes Tree Satch Vore/Save Cop Document Al Causes Cause Causes Causes Causes Causes Causes	Print Cut Copy Passe Sim Setup Cut Time Sim Jake SyntheSim Model Settings Time Boundaries for the Model Info/Pswd Sketch Units Equiv XLS Files Ref Modes Time Boundaries for the Model INITIAL TIME = 0 Initial TIME = 0 FINAL TIME = 100 TIME STEP = 1 Image: Sim Step Image: Sim Step IME STEP = 1 Image: Sim Step Image: Sim Step Image: Sim Step Image: Sim Step IME STEP = 1 Image: Sim Step Image: Sim Step Image: Sim Step Image: Sim Step Image: Sim Step 1 Image: Sim Step Image: Sim Step Image: Sim Step Image: Sim Step Image: Sim Step 1 Image: Sim Step Image: Sim Step	Meality Build Output Centrol Check Windows Windows Panel
Compare (III View 1 [D] Times New Roman [12]b] i [u]s (미국 대학교 (고학 대학	

Start your model of the Taiwanese SARS epidemic at day 0 (enter 0 in the INITIAL TIME box) and simulate for 120 days (enter 120 the FINAL TIME box). Select a time step of 0.25 days by entering 0.25 into the third box. Check the box saying **Save results every TIME STEP**. Also select the **Units for Time** to be Day. For now, leave **Integration Type** at the default setting, Euler. Click **OK**.

Now save your model by selecting the **File>Save As** menu and entering the desired name in the **File Name** field and clicking on **Save**. Enter the name SARS_model_step_1 (VensimPLE will automatically supply the .mdl extension).*

Before beginning to develop your model, make sure the SARS data are loaded. Download <SARSDATA.vdf> if you haven't already, and place the file in your Vensim directory .Then

load the dataset by clicking on ^{Control} to get the control panel (which should look like this):

^{*} Vensim saves every simulation run and custom graph you produce as a separate file. It supplies a **.vdf** extension for simulation runs and a **.vgd** extension for custom graphs. These files cannot be opened from outside the Vensim application; they can be opened from inside Vensim through the **Control Panel**.

Control Panel	
Variable Time Axis Scaling [Datasets Graphs
Available - Info	Loaded - Info
SARSDATA	
	>>
	<<
Delete	Load From
🗌 Keep on top	Close

If you see something different, click on the **Datasets** tab. To load the data file, **SARSDATA**, select it by clicking and then hit the >> button which will move it to the **Loaded** column (navigate via the **Load From...** button if you put the data somewhere else on your computer). The data set is now available.

Note: To access the data, you *must* use *variable names exactly as specified* in this tutorial.

Now you are ready to start building your model.

II. Developing the Stock, Flow, and Feedback Structure

The VensimPLE software is designed using the metaphor of a "workbench." The large blank area in the middle of the screen is your work area, where you develop and analyze your model. The buttons on the border of the work area represent the different tools available as you work on your model. The tools on the top horizontal row are for building your model. The tools on the left vertical bar are for model analysis. The tools on the bottom horizontal row allow you to change the formatting of the model diagram. You will become familiar with many of these tools as you build the epidemic model.

To begin, add a stock representing the population susceptible to SARS to your model. Click on \square

the variable button to activate the stock tool, denoted by a box in the menu on the top horizontal toolbar. Then click in the left center of the screen. Use this tool whenever you want to add a stock (or level variable) to your model.

VensimPLE then returns an empty text box and a blinking cursor. Type the variable name **Population Susceptible to SARS** and then hit the return key. If the variable name does not fit comfortably within the stock, you can re-size the stock by "grabbing" the handle in the lower right corner (place the mouse at the corner to allow you to change modes, then hold down the left mouse button) and moving the mouse. Your screen should now look like this:



You have just created the first variable in your model, the stock of people that could potentially contract SARS.

Now add the stock of people that have contracted the disease. Click on the stock tool button, and then click again about two inches to the right of the susceptible stock. Name this variable **Population Infected with SARS**. Resize if needed. Your screen should now look like this:



Now add the flow of infections that connects the two stocks. Click on the Rate rate button in the top horizontal tool menu. Now, click and release *inside* the stock of susceptible people, then move the cursor so that it sits *inside* the infected stock, then click and release again. VensimPLE then gives you an empty text box and a blinking cursor. Type **Infection Rate** and hit the return key. Your screen should now look like this:



You have now created the flow, **Infection Rate**, which decreases the stock of people susceptible to SARS and increases the stock of those infected. Now you need to add the variables that close the loops between that infection rate and the states of the susceptible and infected stocks. Begin by adding the two auxiliary variables that determine the infection rate, **Infectivity** and **Contacts Between Infected and Uninfected People**.

To add **Infectivity** click on the Variable button and then click again approximately one inch above the infection rate flow. When the text box appears, type **Infectivity** and hit return. To add the next variable, click again, this time about an inch below the infection flow. When the text box appears, type **Contacts Between Infected and Uninfected People.** Unlike the previous variables—which were either stocks or flows—the new variables are not attached to a flow valve or a box. These are called *auxiliary variables*.

To represent that the **Infection Rate** is determined by **Infectivity** and **Contacts Between Infected and Uninfected People**, we connect them with causal arrows.

A,

First click on the button to select the causal arrow tool. Now, click and release on the variable **Infectivity** and then click and release again on **Infection Rate**. Do the same for **Contacts Between Infected and Uninfected People** and **Infection Rate**. Make sure your causal arrows actually end on the word **Infection Rate**. They should *not* be attached to the stocks. You

Tit

can delete arrows or other model objects and variables using the Delete delete tool.

Clicking on the Move/Size move/size button allows you to select the variables you have created and move them to different places on the screen. To do this, place the arrow cursor over the variable you wish to move, hold down the mouse button, move the variable to the desired place, and then release the mouse button. You can also select the "handles" of the causal arrows (the small circles in the middle of the arrow) and change the curvature of the arrow. Arrange your variables and arrows so that your diagram looks approximately like this:



Now, update your diagram to show the polarity of the causal connections. First click on the button. Then select the "handle" of the arrow you wish to label by clicking and releasing on the small circle in the middle of the arrow (the entire arrow is highlighted when selected).

With the arrow still selected, *right click* (Mac users *control click*) to call up a dialog box for your arrow, shown here. Select the correct polarity indications for each of the two causal arrows so your diagram resembles the image below.

Use this same dialog box to move the polarity labels to the other side of the arrow or change arrow width.

You may want to move the handle of each arrow around a little to adjust where its label appears, so that you can make sure that each sign is clearly associated with its causal arrow.

Options for Arrow from Contacts Between Infected and Uninfected People to Infection Rate
Arrowhead Color Delay mark
Line Style/Thickness
Polarity
● None O + O · O S O D O Other I
Position polarity mark at the Font
Arrowhead C Handle on the
Inside Outside of the arrow's curve
OK Cancel



Note that you can select multiple links or variables at the same time by holding down the *shift* key while selecting objects. This is useful for efficiently assigning multiple polarities (the labels denoting + and -).

Now, using the same steps discussed above, add the necessary variables, links, and labels so that your diagram looks like this:



Finally, label the loops you have just created. Use the comment tool to add comments and graphics that, while having no structural use, can greatly help someone else understand your model diagram.

To do this, click on the comment button and then click in the center of the feedback loop. After clicking in the center of the reinforcing loop (the one linking the infection rate and the infected population), you should see the following dialog box:

Ohana	Comr	nent Description Face: Times New Roman Size (Points)
Shape C None C By Type C Box C Clear Box C Circle	 Hexagon Diamond Triangle Up Triangle Loop Clkwse Loop Counter 	@Arial Unicode M: □ Bold 12 @Batang □ Italic @BatangChe □ Underline @DFKai-SB □ Strikethrough @DotumChe □ Vertical @FangSong ✓ Example
⊂Text Position	C Above C Left C Right	Shape color
🔽 Use as arrow j	unction 🗌 no caus	e 📃 Background color
Hide Level		
Comment		
Graphics None O In	mage	O Bitmap O Metafile Import
	ОК	Cancel

To label the reinforcing loop click, on the **Loop Clkwse** button in the **Shape** box; click on **Center** in the **Text Position** box; and type **R** in the **Comment** box. Click on the **OK** button or

hit return. The loop identifier $\stackrel{\mathbb{R}}{\smile}$ will be displayed.

Now select the comment tool again and click below the loop identifier label you just created. Type the name of the loop into the **Comment** field. A good name for this loop is the "Contagion" loop. Click on the **OK** button or hit return. Now you will see the loop type and name together. Repeat this process to label the balancing feedback on the left side of your model diagram, noting that this feedback moves counterclockwise. Name that loop the "Depletion" loop. Your model should now look like:



IMPORTANT: Note that the arrow around each loop identifier flows in the *same* direction as the loop to which it refers. The reinforcing Contagion loop is clockwise in your diagram, so its loop identifier is also clockwise; the Depletion loop on the left moves counterclockwise, so its

identifier moves clockwise. Labeling and naming your loops is important to help your audience see the feedback structure of your model.

III. Specifying Equations for Your Model

Now that you have developed a complete stock, flow, and feedback representation for your initial model of the SARS epidemic, you need to write equations for each of the variables.

f(x)

To begin, click on the equations button on the *top horizontal toolbar*. The variables in your diagram become highlighted.



Highlighting indicates that the equation for that variable is incomplete.

Variables in system dynamics models are classified as either exogenous or endogenous. Exogenous variables are those that are defined independent of other variables of the model. They are functions of time (i.e., Exogenous Variable = f(t)). Of course the exogenous variables may be constants, in which case they are called parameters. Endogenous variables are influenced by other variables in the system (Endogenous Variable = f(x, y, z), where x, y, z are other variables in the model). Your model has three exogenous inputs—Infectivity, Contact Frequency, and the Total Population—and six endogenous variables—Population Susceptible to SARS, Infection Rate, Population Infected with SARS, Probability of Contact with Infected Person, Susceptible Contacts, and Contacts Between Infected and Uninfected People.

Start by writing the equations for the endogenous variables. Begin by clicking on the **Infection Rate.** You then see the following dialog box:

Edit: Infection Rate
Variable Information Edit a Different Variable
Name Infection Rate
Contacts Between Infected and Un
Type Auxiliary V Sub-Type Normal V Sub-Type Norm
New Variable FINAL TIME
Check Units Supplementary
Group Group Later Min Max Back to Prior Edit Infectivity
Jump to Hilite INITIAL TIME
Equations
· · · · · · · · · · · · · · · · · · ·
Functions Common - Keypad Buttons - Variables Canaco
ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People
DELAY FIXED _ 4 5 6 - :0R: Infectivity
DELAYII 1 2 3 * :NOI:
DELAYS DELAYST O E . / :NA:
$\langle \text{GET} 123 \text{ DATA} \rangle \rangle = \langle \langle \rangle =$
Undo -> {[()]}
Comment
Expand The second secon
Errors: Incorrect/Incomplete Equation
ok check syntax check model belete variable cancel help

Good modeling practice requires that each equation in a model have three elements: (1) *the equation itself;* (2) *specified units of measure; and* (3) *complete documentation.*

You'll be entering the equation in the box adjacent to the word **Equations** and the units of measure in the text field to the right of the word **Units**. Equation documentation is entered in the box to the right of the word **Comment**.

Begin writing the equation first by clicking in the equations box. Now, look in the box below it on the right, where **Causes** are listed. Here Vensim has provided you with the two variables that your model diagram shows as influencing the infection rate, **Contacts Between Infected and Uninfected People** and **Infectivity**. A simple and plausible formulation for the infection rate is simply to multiply the number of contacts by the infectivity (which, by definition, is the fraction of contacts that result in transmission of the disease, or equivalently, the conditional probability of transmission given a contact between an infected and susceptible individual). To enter this equation first click on the **Contacts Between Infected and Uninfected People** variable, which will now appear in the equation box. Now either click on or type "*" to represent multiplication. Complete the equation by clicking on **Infectivity**. Your dialog box should now look like this:

Edit Infection Rate Variable Information Name Infection Rate Type Auxiliary Sub-Type Normal Yer Auxiliary Sub-Type New Variable Search Model New Variable New Variable Back to Prior Edit Infection Rate Infections Contacts Between Infected and Ur Group .sars tutorial model step Min Max Jump to Hilite Infectivity Infectivity Infectivity Equations Contacts Between Infected and Uninfected People Delayin Infectivity Delayin Infectivity Infectivity Infectivity Delayin Infectivity Delayin Infectivity <th></th> <th></th>		
Variable Information Fait a Different Variable Name Infection Rate Type Auxiliary Sub-Type Normal Contacts Between Infected and Ur Contacts Between Infected and Ur Group .sars tutorial model step Min Max Equations Contacts Between Infected and Uninfected People*Infectivity Infection Rate Infectivity INITIAL TIME INITIAL TIME Infectivity Infectivity	Edit: Infection Rate	
Name Infection Rate Type Auxiliary Sub-Type Normal Contact Frequency Contacts Between Infected and Ur Units Check Units Supplementary Back to Prior Edit Jump to Hilite Infectivity INITIAL TIME Infectivity INITIAL TIME Functions Contacts Between Infected and Unifected People*Infectivity Functions Common Keypad Buttons Variables Causes Contacts People I 2 3 • :NOT: EXP EXP GET 123 CONSTANTS GET 123 DATA I 0 K I 1 4 4 1 <lii 1="" 1<="" 4="" li=""> I 1 4 4 1 I 1 4</lii>	Variable Information	-Edit a Different Variable
Type Auxiliary Sub-Type Normal Units Check Units Supplementary Search Model New Variable FINAL TIME Infection Rate Infectivity INITIAL TIME Equations Contacts Between Infected and Uninfected People*Infectivity Functions Common Keypad Buttons Variables Contacts Between Infected and Uninfected People*Infectivity ABS DELAY FIXED DELAY11 DELAY3 DELAY3 Cert 123 DATA Gert 123 DATA Gert 123 DATA Causes Contacts Between Infected People Infectivity Delay31 EXP Constants Contacts People Contacts Peo	Name Infection Rate	All Contact Frequency
Units Check Units Check Units Supplementary Group sars tutorial model step Min Max Equations Contacts Between Infected and Uninfected People*Infectivity New Variable Back to Prior Edit Infection Rate Infectivity Infectivity Infectivity Equations Contacts Between Infected and Uninfected People*Infectivity ABS DELAY 1 DELAY 11 DELAY 11 DELAY 11 DELAY 12 DELAY 30 DELAY 12 DELAY 12 DELAY 12 DELAY 12 DELAY 12 DELAY 12 DELAY 13 Constants DELAY 14 DELAY 15 DELAY 16 DELAY 17 DELAY 16 DELAY 16 <td>Type Augilians - Sub-Type Normal</td> <td>Search Model Contacts Between Infected and Ur</td>	Type Augilians - Sub-Type Normal	Search Model Contacts Between Infected and Ur
Units Check Units Supplementary Back to Prior Edit Infection Rate Infectivity Back to Prior Edit Infectivity Infection Rate Infectivity Infection Rate Infection Rate Infection Rate Infectivity Infection Rate Infectivity Infection Rate Infectivity Infection Rate Infectivity Infectivity <td>Auxillary V Sub Type Normal</td> <td>New Variable EINAL TIME</td>	Auxillary V Sub Type Normal	New Variable EINAL TIME
Group .sars tutorial model step Min Max Back to Prior Edit Jump to Hilite Infectivity Equations Contacts Between Infected and Uninfected People*Infectivity Infectivity Infectivity Functions Conmmon Keypad Buttons Variables Causes Image: Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY FIXED 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY IN E 4 5 6 - :OR: Infectivity DELAYII E 4 5 6 - :OR: Infectivity DELAY3 DELAY3 0 E / :NA: Contacts Detween Infected and Uninfected People GFT 123 DATA > > = > > = GFT 123 DATA Infectivity Infectivity GFT 123 DATA Infectivity Infectivity	Units Check Units Supplementary	Infection Rate
Group .sars tutorial model step Min Max Equations Contacts Between Infected and Uninfected People*Infectivity Functions Conumon Functions Common ABS 7 DELAY FIXED DELAY1 DELAY1 DELAY1 DELAY1 DELAY3 DELAY3 DELAY3 DELAY1 DELAY3 DELAY3 DELAY1 DELAY3 DELAY1 DELAY3 DELAY3 DELAY3 DELAY3 DELAY3 DELAY1 DELAY1 DELAY3 DELAY DELAY DELAY DELAY DELAY DELAY DELAY DELAY	Group May	Back to Prior Edit Infectivity
Equations Contacts Between Infected and Uninfected People*Infectivity Functions Common Keypad Buttons Variables Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY FIXED 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY1 1 2 3 * :NN: Contacts Between Infected and Uninfected People DELAY1 0 E / :NA: 0 E / :NA: DELAY3 0 E / :NA: 0 E / :NA: GET 123 CONSTANTS > = < < Image: Constraints GET 123 DATA > = < < GET 123 LOOKUPS 1 1	Gloup sars tutorial model step V Min Max	Jump to Hilite INITIAL TIME
Functions Common Keypad Buttons Variables Causes ABS 7 8 9 + :AND: DELAY FIXED 4 5 6 - :OR: DELAY1 1 2 3 * :NA: DELAY3 0 E / :NA: Contacts Between Infected and Uninfected People DELAY1 1 2 3 * :NA: DELAY3 0 E / :NA: QET 123 DATA > = < <=	Equations Contacts Between Infected and Uninfected People*Infectivit	ty A
Functions Common Keypad Buttons Variables Causes Image: Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY1 I 2 3 * :NOT: Contacts Between Infected and Uninfected People DELAY11 I 2 3 * :NOT: Contacts Between Infected and Uninfected People DELAY11 DELAY3 0 E . / :NA: Infectivity DELAY3 0 E . / :NA: . / .> . GET 1/23 CONSTANTS		
Functions Common Keypad Buttons Variables Causes Image: Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY FIXED 4 5 6 - :OR: Iffectivity DELAY1I 1 2 3 :NOT: Iffectivity Iffectivity DELAY3I 0 E / :NA: . . . QET 123 CONSTANTS GET 123 LONSTANTS GET 123 LONSTANTS 		
Functions Common Keypad Buttons Variables Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY FIXED 4 5 6 - :OR: Contacts Between Infected and Uninfected People DELAY11 1 2 3 * :NOI: Contacts Between Infected and Uninfected People DELAY31 0 E / :NA: () / · QET 123 CONSTANTS >> = < <=		
Functions Common Keypad Buttons Variables Causes Image: Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY1 4 5 6 - :OR: Infectivity DELAY1 1 2 3 * :NA: Infectivity DELAY3 0 E / :NA: Infectivity DELAY3 0 E / :NA: Infectivity GET 123 ONSTANTS >> = < <=		
Functions Common Keypad Buttons Variables Causes Image: Common		
Functions Common Keypad Buttons Variables Causes Image: Common		
Functions Common Keypad Buttons Variables Causes ABS 7 8 9 +<:AND:		-
ABS 7 8 9 + AND: DELAY FIXED 4 5 6 - :OR: DELAY1 1 2 3 + :NOT: DELAY3 0 E . / :NA: QET 123 CONSTANTS QET 123 DATA 	Functions Venichles Venichles	
ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY FIXED 4 5 6 - :OR: DELAY1 4 5 6 - :OR: DELAY1 1 2 3 * :NOT: DELAY3 0 E . / :NA: GET 123 CONSTANTS GET 123 DATA I 1 GET 123 LOONIPS 	Functions Common variables	Causes
DELAY FIXED = 4 5 6 - :OR: Infectivity DELAY1 DELAY1 1 2 3 * :NOT: Infectivity DELAY1 DELAY3 0 E . / :NA: . DELAY31 0 E . / :NA: . . . GET 123 CONSTANTS GET 123 DATA GET 123 LOONIPS .	ABS ABS 7 8 9 + :AND: Contacts Bet	ween Infected and Uninfected People
DELAYII23*:NOT:DELAYII0E. \checkmark :NA:DELAY3I0E. \checkmark :NA:DELAY3I0E. \checkmark :NA:GET 123 CONSTANTS \land GET 123 DATAGET 123 LOOKUPS	DELAY FIXED _ 4 5 6 - :OR: Infectivity	
DELAY3 DELAY3I EXP0E \checkmark \land 0E \checkmark \land \land 0E \land \land \land 0E \land \land \land 0E \land \land \land 0E \land \land <tr< td=""><td></td><td></td></tr<>		
DELAY3I U E · </td <td>DELAY3</td> <td></td>	DELAY3	
EXP () , ^ <> GET 123 CONSTANTS > >= < < <=	DELAY3I U E . / :NA:	
GET 123 CONSTANTS $\rightarrow \geq = < < =$ GET 123 LOOKUPS L		
	$(\text{GET 123 CONSTANTS}) \rightarrow \rangle = = \langle \langle \rangle = \langle \rangle \rangle$	
	GET 123 LOOKUPS	
GET DIRECT CONSTANTS	GET DIRECT CONSTANTS	
Comment	Comment	
Expand -	Expand	-
Errors: Equation Modified	Errors: Equation Modified	v
OK Check Syntax Check Model Delete Variable Cancel Help	OK Check Syntax Check Model Delete	Variable Cancel Help

Now fill in the units. **Infection Rate** represents flow of people through time, so the appropriate unit of measure for this equation is people/time unit. Since you already chose to run the model in time steps of 1 day, the appropriate unit is people/day. Type **People/Day** in the **Units** field.

(The next time you specify the units for a variable in this model, People/Day will appear in the units pull-down menu. You can then click on the arrowhead to the right of the units field to see units already specified for other variables in the model, and then select units you've already defined from that list as appropriate.)

Finally, provide a description of this equation in the comment field. A good comment will be brief but also explain the logic behind the equation and state the key assumptions. For example, one might write for this equation:

The infection rate is determined by the total number of contacts between infected and uninfected people each day and the probability that each such contact results in transmission from the infected to uninfected person (denoted infectivity).

Your dialog box should now look like this:

Variable Information Edit a Different Variable Name Infection Rate Ype Auxiiary Sub-Type Normal Ali Contact Frequency Contact Between Infected and Un Reveal and Uniffected People*Infectivity Back to Prior Edit Infection Rate Infections Contacts Between Infected and Uniffected People*Infectivity Unut to People Infection Rate Infections Contacts Between Infected and Uniffected People*Infectivity Infections Contacts Between Infected and Uniffected People*Infectivity Infections Contacts Between Infected People*Infectivity Infectivity Infectivity	Edit: Infection Rate	
Name Infection Rate Type Auxiliary Sub-Type Normal Image: Search Model Contacts Brewsen Infected and Unifected People Units People/Day	-Variable Information	- Edit a Different Variable
Type Auxiliary Sub-Type Normal Units People/Day Check Units Supplementary Group .sars tutorial model step Min Max Equations Contacts Between Infected and Uninfected People*Infectivity Equations Contacts Between Infected and Uninfected People*Infectivity Functions Common Keypad Buttons Variables Causes Functions Common Functions Co	Name Infection Rate	All Contact Frequency
Type Auxiliary Sub-Type Normal Search Model Chumlative Reported Cases Units People/Day Check Units Supplementary New Variable Finkl TiME Back to Prior Edit Infection Rate Infectivity Infectivity Equations Contacts Between Infected and Uninfected People*Infectivity INITIAL TIME Functions Common Keypad Buttons Variables Causes PELAY FIXED 7 8 + i:AND: Contacts Between Infected People DELAY FIXED 7 8 + i:AND: Contacts Between Infected People DELAY FIXED 7 8 + i:AND: Contacts Between Infected and Uninfected People DELAY FIXED 9 + i:AND: Contacts Between Infected and Uninfected People DELAY FIXED 9 + i:AND: Contacts Between Infected and Uninfected People DELAY FIXED 9 + i:AND: Contacts Between Infected and Uninfected People DELAYII 9 - i:AN: Contacts Between infected and uninfected People each GeT 123 CONSTANTS - i ((i)) - i ((i)) - i ((i)) Comment The infectio		Contacts Between Infected and Ur
Units People/Day Check Units Supplementary New Variable FINAL TIME Group .sars tutorial model step Min Max Jump to Hilte Infection Rate Equations Contacts Between Infected and Uninfected People*Infectivity Jump to Hilte Infection Rate Functions Common Keypad Keypad Variables Causes ✓ ABS 7 8 9 + :AND: Contacts Detayin Infectivity DELAYI I 2 3<<:NOT:	Type Auxiliary 🗸 Sub-Type Normal 🗸	Search ModelCumulative Reported Cases =
Group .sars tutorial model step win Max Back to Prior Edit Jump to Hilte Infection Rate Infectivity Equations Contacts Between Infected and Uninfected People*Infectivity Infectivity Functions Contacts Between Infected and Uninfected People*Infectivity Infectivity Functions Contacts Between Infected and Uninfected People*Infectivity Infectivity ABS 7 8 9 + :AND: Infectivity DELAY FIXED 4 5 6 :00R: Infectivity DELAYII 2 3<<::NOT: Infectivity Contacts Between Infected and Uninfected People DELAYII 0 E . :NA: Infectivity OE OB Infectivity OE 	Units People/Day	New Variable FINAL TIME
Group .sars tutorial model step Min Max Jump to Hilite Infectivity Equations Contacts Between Infected and Uninfected People*Infectivity Infectivity Infectivity Functions Common Keypad Buttons Variables Causes Infected People ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY FIXED 4 5 6 - :OR: Infectivity DELAY1 4 5 6 - :OR: Infectivity DELAY1 0 E / :NN: Infectivity DELAY1 0 E / :NN: Infectivity DELAY3 0 E / :NN: Infectivity Contacts Detween Infected and Uninfected People Infectivity Infectivity DELAY3 0 E / :NN: Infectivity Comment The infection rate is determined by the total number of contacts between infected and uninfected people each and day and the probability that each such contact results in transmission from the infected to uninfected person * Comment The infectivity). - - * Expan	· · · · · · · · · · · · · · · · · · ·	Back to Prior Edit
Equations Contacts Between Infected and Uninfected People*Infectivity - Functions Common ABS - 7 8 9 + :AND: DELAY FIXED - 2 4 : 0 : 0 : 0 : 0 : 0 : 0 : 0 : 0 : 0 :	Group .sars tutorial model step 🗸 Min 🛛 Max	Tume to Wilite INITIAL TIME
Equations Contacts Between Infected and Uninfected People*Infectivity Functions Common Functions Common ABS Contacts Between Infected and Uninfected People DELAY FIXED 7 DELAY FIXED 7 DELAY INTERCHARL 4 DELAY INTERCHARL 4 DELAY INTERCHARL 6 DELAY INTERCHARL 0 E / DELAY INTERCHARL 0 DELAY INTS 0 C() ^ V :NA: () / () ^ V :NA: () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / <		Jump to HITTLE TIME
Functions Common Keypad Buttons Variables Causes Image: Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY INDELAY31 1 2 3<:NOT:	Contacts Between Infected and Uninfected People*Infectiv	rity 🔺
Functions Common Keypad Buttons Variables Causes Causes ABS 7 8 9 + AND: Contacts Between Infected and Uninfected People DELAY FIXED 4 5 6 - 10R: Infectivity Infectivity DELAY11 0 E . :NAT: Infectivity Infectivity DELAY31 0 E . :NAT: Infectivity Infectivity Infectivity Infectivity Infectivity CBT 123 CONSTANTS 0 E .<		
- Functions Common • Keypad Buttons Variables Causes • ABS DELAY FIXED DELAY1 DELAY1 DELAY1 DELAY3		
Functions Common Keypad Buttons Variables Causes Image: Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY1 4 5 6 - :OR: Infectivity DELAY1 0 E / :NOT: Infectivity DELAY3 0 E / :NOT: Infectivity GET 123 CONSTANTS 0 / :NOT: Infectivity GET 123 CONSTANTS 0 / :NOT: Infectivity GET 123 CONSTANTS 0 / :NOT: Image: Causes GET 123 CONSTANTS 0 / :NOT: Image: Causes GET 123 LOOKUPS Image: Causes Image: Causes Image: Causes Comment The infection rate is determined by the total number of contacts between infected and uninfected people each advand the probability that each such contact results in transmission from the infected to uninfected person advant the infectivity). Expand Image: Cause Image: Cause Image: Cause OK Check Syntax Check Model Delete Variable Cancel		
Functions Common Keypad Buttons Variables Causes Image: Causes ABS PELAY FIXED		
Functions Common Keypad Buttons Variables Causes ABS 0 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY FIXED 4 5 6 - :OR: Infectivity DELAYII 0 E / :NOT: 0 E / :NOT: DELAY3I 0 E / :NA: OFT 123 DATA 0 E / :NA: OFT 123 DATA GET 123 LOOKUPS GET DIRECT CONSTANTS Comment The infection rate is determined by the total number of contacts between infected and uninfected people each aday and the probability that each such contact results in transmission from the infected to uninfected person aday and the probability that each such contact results in transmission from the infected to uninfected person aday and the probability that each such contact results in transmission from the infected to uninfected person aday and the probability that each such contact results in transmission from the infected to uninfected		
Functions Common Keypad Buttons Variables Causes ABS 7 8 9 + :AND: Contacts Between Infected and Uninfected People DELAY1 4 5 6 - :OR: Infectivity DELAY1 1 2 3 + :NOT: Infectivity DELAY1 0 E / :NA: Infectivity DELAY3 0 E / :NA: Infectivity GET 123 CONSTANTS 0 E / :NA: Infectivity GET 123 LOCKUPS I I { : NA: Infectivity Comment The infection rate is determined by the total number of contacts between infected and uninfected people each of day and the probability that each such contact results in transmission from the infected to uninfected person of (denoted infectivity). Image: Contact is in transmission from the infected is people each of day and the probability that each such contact results in transmission from the infected to uninfected person of (denoted infectivity). Image: Contact is people each of the infectivity. Errors: Equation Modified Image: Contact is people each of the infectivity. Image: Contact is people each of the infectivity. OK Check Syntax Check Model Delete Variable <		
Functions Common Keypad Buttons Variables Causes ✓ ABS DELAY FIXED DELAY1 DELAY1 DELAY1 DELAY3 DELA		
Functions Common Keypad Buttons Variables Causes ABS DELAY FIXED 7 8 9 + :AND: DELAY FIXED 4 5 6 - :OR: DELAYII 1 2 3 * :NOT: DELAYII 0 E / :NA: Infectivity DELAYI 0 E / :NA: Infectivity OET 123 CONSTANTS 0 E / :NA: Infectivity QFT 123 DATA 0 E / :NA: Infectivity QFT 123 LORKUPS I I () / · · · GET 123 LOOKUPS I I () / · · · GET 123 LOOKUPS I I () / · · · GET 123 LOOKUPS I I () / · · · GET 123 LOOKUPS I I () / · · · GET 123 LOOKUPS I I () / · · · Get 123 LOOKUPS I I I / · · · GET officities I I I / · · ·		-
ABS 7 8 9 + :AND: Causes Causes Image: Causes	- Functions - a Voyned Buttons Variables	
ABS 7 8 9 + :AND:: Contacts Between Infected and Uninfected People DELAYI DELAYI 4 5 6 - :OR: DELAYI 1 2 3 * :NOT: Infectivity DELAYI 0 E . / :NA: . Infectivity DELAY3 0 E . / :NA: . . . OET 123 CONSTANTS 0 E . / :NA: . . . GET 123 DATA GET 123 LOCKUPS Undo -> . <td>Functions Common Valiables</td> <td>Causes 🔽</td>	Functions Common Valiables	Causes 🔽
DELAY FIXED = 4 5 6 : OR: Infectivity DELAYI DELAYI = 4 5 6 -: OR: Infectivity DELAYI DELAYI = 4 5 6 -: OR: Infectivity DELAYI DELAYI = 4 5 6 -: OR: Infectivity DELAYI DELAYI = 0 E . .: NA: DELAYI DELAYI = .: NA: OFT 123 CONSTANTS GET 123 LOOKUPS GET 123 LOOKUPS GET 123 LOOKUPS GET 123 LOOKUPS GET 01RECT CONSTANTS Comment The infection rate is determined by the total number of contact	ABS 🔺 7 8 9 + :AND: Contacts B	etween Infected and Uninfected People
DELAYI I <td>DELAY FIXED 4 5 6 - OR. Infectivit</td> <td>У</td>	DELAY FIXED 4 5 6 - OR. Infectivit	У
DELAY1 1 2 3 * :NOT: DELAY3 DELAY3 0 E . / :NA: EXP 0 E . / :NA: . . GET 123 CONSTANTS GET 123 DATA GET 123 LOOKUPS GET 123 LOOKUPS .	DELAY1	
DELAY3 DELAY3 EXP GET 123 CONSTANTS GET 123 DATA GET 123 LOCKUPS GET 123 LOCKUPS GET DIRECT CONSTANTS Undo -> {[()]} Comment The infection rate is determined by the total number of contacts between infected and uninfected people each day and the probability that each such contact results in transmission from the infected to uninfected person expand Errors: Equation Modified V OK Check Syntax Check Model Delete Variable Cancel	DELAY11 1 2 3 * :NOT:	
DeltaTor EXP GET 123 CONSTANTS GET 123 DATA GET 123 LOOKUPS GET 123 LOOKUPS GET 123 LOOKUPS GET 123 LOOKUPS Undo Undo -> {[[]]} Undo -> {[[]]} Comment The infection rate is determined by the total number of contacts between infected and uninfected people each day and the probability that each such contact results in transmission from the infected to uninfected person (denoted infectivity). Errors: Equation Modified V OK Check Syntax Check Model Delete Variable Cancel Help	DELAYS O E . / :NA:	
GET 123 CONSTANTS GET 123 CONSTANTS GET 123 DATA GET 123 LOOKUPS Comment The infection rate is determined by the total number of contacts between infected and uninfected people each day and the probability that each such contact results in transmission from the infected to uninfected person GET 123 LOOK Errors: Equation Modified OK Check Syntax Check Model Delete Variable Cancel	FXP () ()	
GET 123 DATA >>= < <=	GET 123 CONSTANTS	
GET 123 LOOKUPS I I I GET DIRECT CONSTANTS Image: Undo -> ([()]) Image: Undo -> ([()]) Comment The infection rate is determined by the total number of contacts between infected and uninfected people each day and the probability that each such contact results in transmission from the infected to uninfected person (denoted infectivity). Expand Errors: Equation Modified V OK Check Syntax Check Model Delete Variable Cancel Help	GET 123 DATA >>= = < <=	
GET DIRECT CONSTANTS Undo -> {[[()]} Comment The infection rate is determined by the total number of contacts between infected and uninfected people each day and the probability that each such contact results in transmission from the infected to uninfected person (denoted infectivity). Expand Expand OK Check Syntax Check Model Delete Variable Cancel Help	GET 123 LOOKUPS	
Comment The infection rate is determined by the total number of contacts between infected and uninfected people each day and the probability that each such contact results in transmission from the infected to uninfected person (denoted infectivity). Expand (denoted infectivity). Errors: Equation Modified OK Check Syntax	GET DIRECT CONSTANTS	
Comment The infection rate is determined by the total number of contacts between infected and uninfected people each day and the probability that each such contact results in transmission from the infected to uninfected person (denoted infectivity). Expand Expand OK Check Syntax Check Model Delete Variable Cancel Help		
day and the probability that each such contact results in transmission from the infected to uninfected person Expand day and the probability that each such contact results in transmission from the infected to uninfected person Errors: Equation Modified OK Check Syntax Check Model Delete Variable Cancel Help	Comment The infection rate is determined by the total number of	contacts between infected and uninfected people each
Expand (denoted infectivity). Errors:Equation Modified OK Check Syntax Check Model Delete Variable	day and the probability that each such contact results i	n transmission from the infected to uninfected person
Errors: Equation Modified OK Check Model Delete Variable Cancel	(denoted infectivity).	
Errors: Equation Modified OK Check Syntax Check Model Delete Variable Cancel Help		
OK Check Syntax Check Model Delete Variable Cancel Help	Errors: Equation Modified	
OK Check Syntax Check Model Delete Variable Cancel Help	Induction Modified	
	OK Check Syntax Check Model Delet	e Variable Cancel Help

Click on **OK** or hit return and your diagram will look like this:



The Infection Rate is no longer highlighted, indicating that you have specified its equation.

Now write the equation for the stock of susceptible people. Begin by clicking on the **Population Susceptible to SARS** stock. You should get a dialog box that looks like the following:

Edit: Population Suscep	tible to SARS					
-Variable Informa	ation				-Edit a Different	Variable
Name Population	Suscentible to S	SARS			à11	Contact Frequency
						Contacts Between Infected and Ur
Type Level	 Sub-Type 		•		Search Model	Cumulative Reported Cases 🛛 🗏
Units		- Checi	k Units 🗌 🗆 Su	pplementary	New Variable	FINAL TIME
				-	Back to Prior Ed	it Infectivity
Group sars tuto	rial model step 💌	- Min	Max		Jump to Hilite	INITIAL TIME
-EquationsInfo	ection Rate					
						T
Initial						
varue						
- Functions - C	ommon 💌	— Кеура	d Buttons	Variables	Causes	_
ABS		7 8	9 + :AND:	Population :	Susceptible to SAR	S
DELAY FIXED	[_ 4 5	6 - :OR:	Infection R	ate	
DELAY1I DELAY1I		$\frac{1}{1}$	3 * :NOT:			
DELAY3		0 5	- ·Nλ·			
DELAY3I			· / .NA.	1		
GET 123 CONSTANT	s					
GET 123 DATA		> >=	= < <=			
GET 123 LOOKUPS		_ []]	! { }			
GET DIRECT CONST.	ANIS	Undo	-> {[()]}	1		
Comment						
Comment						·
Expand						-
Errors: Incorrect	/Incomplete Equat	ion				•
OK	Check Syntax		Check Model	Delete	Variable C	ancel Help

You enter the equation for the stock in the equation box. The value of a stock at any moment in time is equal to the sum of all that stock's inflows less all of its outflows from the start time of the simulation, plus the initial value. In the Windows version of VensimPLE, the term **Integ** appears to the left of the equation box, indicating that its value is an integral; the current Mac version omits this term.^{*}

When you created the stock, flow, and feedback diagram, you made the **Infection Rate** an outflow from the stock of **People Susceptible to SARS**. VensimPLE captures this stock-flow relationship by identifying the **Type** for the susceptible stock as **Level** (level is another term for stock). This means that at any point in time the susceptible stock is equal to its initial condition less all the people that have flowed out of it, up to that point in time.

Now we need to specify the initial value for the susceptible stock. You enter it in the box just to the right of the words **Initial Value**. Initial conditions can either be numbers or other variables in

* Stock = INTEG(Inflow – Outflow) with an Initial Value of Stock(t₀) is equivalent to: $Stock(T) = \bigcup_{t_0}^{T} (Inflow(t) - Outflow(t)) dt + Stock(t_0)$

Note: Do not write "INTEG" in the equation box, Vensim automatically returns the integral of the equation (when variable type is level).

a model. It is usually better to initialize a stock in terms of a parameter (or combinations of parameters), because you can then alter that parameter easily for sensitivity and policy testing. In this case initialize the stock based on another variable, specifically the **Total Population**. Enter **Total Population** in the **Initial Value** box.

Your equation for the **Population Susceptible to SARS** indicates that the susceptible population is equal to the initial value at the start of the simulation less all of those people who have subsequently contracted the disease.

You still need to specify the unit of measure and document your equation in the comment field. The **Population Susceptible to SARS** is a stock and is measured number of people, so go ahead and add **People** to the **Units** box, then document the equation. A sample comment for **Population Susceptible to SARS** is:

The Population Susceptible to SARS is the equal to the population susceptible prior to the onset of the disease less all of those that have contracted it. It is initialized to the Total Population, which assumes that all individuals are initially susceptible (no prior natural or vaccine-conferred immunity).

After completing the dialog box, click **OK** or press return. Your model diagram should now look like this:



Following a similar process to the one outlined above, you should now be able to specify equations for the remaining endogenous variables, **Susceptible Contacts, Contacts Between Infected and Uninfected People**, and **Probability of Contact with Infected Person**:

Susceptible Contacts= Population Susceptible to SARS*Contact Frequency (People/Day)

Contacts Between Infected and Uninfected People= Susceptible Contacts*Probability of Contact with Infected Person (People/Day)

Probability of Contact with Infected Person= Population Infected with SARS/Total Population (Dimensionless)

Finally, you need to specify equations for the exogenous variables, **Infectivity, Contact Frequency,** and **Total Population**. Begin with **Total Population**. Clicking on it should bring up the following dialog box:

7	
Edit: Total Population	
Variable Information	Edit a Different Variable
Name Total Population	All Contact Frequency
Type Genetert - Sub-Type News 1	Search Model Contacts Between Infected and Ur
Type constant	Now Variable FINAL TIME
Units Check Units Supplementary	Derive Price Edit
Group sars tutorial model sten - Min Max Incr	Back to Frior Ealt Infectivity
	Jump to Hilite INITIAL TIME
-Equations-	
	_
Functions Common Variables	Causes
ABS 7 8 9 + :AND:	
DELAY FIXED _ 4 5 6 - :OR:	
DELAYII 1 2 3 * :NOT:	
DELAY3	
DELAY3I	
GET 123 CONSTANTS	
GET 123 DATA	
GET 123 LOOKUPS	
GET DIRECT CONSTANTS Undo -> {[()]}	
Comment	
Contreller	
Expand	-
Errors: Incorrect/Incomplete Equation	v
OK Check Syntax Check Model Delet	e Variable Cancel Help

Note first that there are no inputs to Total Population, just as you specified in the diagram, indicating that Total Population will be a constant. The data suggest that in Taiwan, the cumulative number of cases eventually rose to approximately 350, so start with that value for **Total Population** (you may want to revisit this assumption later). You also need to specify units of measure and provide a comment. When you are finished your dialog box will look like this:

Edit: Total Population	
Variable Information	-Edit a Different Variable
Name Total Population	All Contact Frequency
Type Constant V Sub-Type Normal V	Search Model Contacts Between Infected and Ur
Unite Decel	New Variable FINAL TIME
Units People Check Units Supplementary	Back to Prior Edit
Group .sars tutorial model step - Min Max Incr	Jump to Hilite INITIAL TIME
Equations 350	
- 330	
	· · · · · · · · · · · · · · · · · · ·
Functions Common Variables	Causes
ABS 7 8 9 + :AND:	
DELAY FIXED = 4 5 6 - :OR:	
DELAY1I 1 2 3 * :NOT:	
DELAY3 DELAY3 DELAY3	
EXP () . ^ <>	
GET 123 CONSTANTS	
GET 123 DATA	
GET DIRECT CONSTANTS	
Comment Total population in this initial model is set to the tota	l number of cumulative cases at the end of the
epidemic in Taiwan.	
Expand	·
Errors: Equation Modified	_
OK Check Syntax Check Model Delete	Variable Cancel Help

Following this example, complete the equations for the other two parameters, **Contact Frequency** (People/Day) and **Infectivity** (dimensionless). **Contact Frequency** represents the number of contacts between infected and uninfected people every day. **Infectivity** represents the probability that each episode of contact results in transmission of the infection.

At this point, you do not have specific data for the values of these parameters. Use your own judgment to determine appropriate values—make a reasonable guess. Later we will discuss how you can test the model's sensitivity to these assumptions.

Finally, set an appropriate initial value, units, and comment for the **Population Infected with SARS**, using your judgment to select what you consider a reasonable initial numerical value.

Now we will add something extra to allow us to compare the behavior of the model to the data for the SARS epidemic in Taiwan. You've loaded a file containing these data (SARSDATA.vdf). To compare the model against the data we need to create variables that correspond to the incidence of new cases, which in the original dataset is denoted **New Reported Cases**, and the prevalence of SARS, denoted **Cumulative Reported Cases**. Because the data file uses these variable names you must create variables in your model with exactly the same names.

Use the stock variable tool $\frac{\Box}{Variable}$ to create a new stock called **Cumulative Reported Cases**,

placing it a few inches below the current structure. Then use the flow tool Rate to create an inflow to that stock. Do this by first clicking and releasing in the blank space to the left of your new stock, then moving your cursor to inside the stock and clicking and releasing again. Call this

flow **New Reported Cases.** The new structure captures the relationship between incidence and prevalence: As new cases are reported, the cumulative number of cases increases. Your diagram should look similar to the following:



To define **New Reported Cases** as equal to the infection rate you could simply draw a causal arrow from the **Infection Rate** to **New Reported Cases**. However, doing so would clutter the

diagram. Instead, we will use a *Shadow Variable*. Select the Shadow Variable tool Shadow Variable from the

Variable to add to sketch				
Contact Frequency Contacts Between Infected and Uninfected Pe Cumulative Reported Cases FINAL TIME				
Infection Rate				
New Benorted Cases				
Population Infected with SARS				
Population Susceptible to SARS	1			
SAVEPER				
Susceptible Contacts				
Name or Infection Rate Pattern				
Type All 🗸	Ī			
OK Exact Cancel				

top toolbar. Click about an inch to the left of **New Reported Cases**. The dialog box shown on the left will pop up, listing all variables in the model. Select the **Infection Rate**, then click OK.

Vensim creates a copy (Shadow) of the **Infection Rate**. Shadow variables are gray and placed within braces: **<Infection Rate>**. Your diagram should now look like this:



Shadow variables enable you to keep your model diagrams clean and readable. Draw a causal arrow from the shadow **<Infection Rate>** to **New Reported Cases**:



Use the equation tool to define **New Reported Cases** as equal to the **Infection Rate**. The units for **New Reported Cases** are People/Day. Add an appropriate comment (point out that you are assuming that new cases are reported immediately). Now define the stock of **Cumulative Reported Cases**. You will see that **Cumulative Reported Cases** is already defined as the integral (accumulation) of **New Reported Cases**. You need to supply the initial number of reported cases, which is zero. Specify the units as People and add an appropriate comment.

By setting **New Reported Cases** to equal the **Infection Rate** we've made a choice to ignore potential differences between the two. In reality there is a delay between infection, diagnosis, and reporting through the public health system. In addition, diagnosis is imperfect (some actual SARS cases were missed; other respiratory diseases might be incorrectly classified as SARS). Modeling both diagnostic errors and reporting delays is straightforward, but we will not do so in this tutorial.

Similarly, you may have noticed that in this model **Cumulative Reported Cases** will equal the actual **Population Infected with SARS**, because you have assumed that **New Reported Cases** equals the actual **Infection Rate**. Why then bother to define **Cumulative Reported Cases** separately from the **Population Infected with SARS**? There are two reasons. First, they are conceptually different: the actual number of people infected with SARS differs from the number reported through the public health surveillance system (there may be delays and measurement errors you might want to capture later). Second, you might later alter the model structure so that the equivalence of the two stocks no longer holds (for example, capturing the rates of recovery and mortality from SARS).

IV. Using the Model Structure Analysis Tools

You are now ready to analyze your model. VensimPLE provides several tools for analyzing and understanding the structure of your model.

By far the most important of these is the unit-checking function. To access this tool, go to the **Model** menu and select **Units Check**. An important feature of any system dynamics equation is *dimensional consistency*. This is just a fancy way of saying that the units of measure must be the same on both the left and right sides of the equation. For example, if you have followed the instructions in the tutorial so far and you run the units check, you will get the following message:



Followed by:



The problem is that the equation for **Susceptible Contacts** is not dimensionally consistent: The right and left sides of the equation have different units. **Susceptible Contacts** is measured in contacts per day, but, in the current formulation, multiplying the **Population Susceptible to SARS** by the **Contact Frequency** yields a value with units of People*People/Day.

The cause of the problem is that unit of measure for **Contact Frequency** is incorrect. The **Contact Frequency** represents the number of contacts *each* person makes per day, not the total number of contacts (which is captured by the variable **Susceptible Contacts**). To fix this problem, change the units of measure for contact frequency to be People/Person/Day[†]. After you do this, run the units check again. When you are done click **OK**. Now when you run the units check you should get the following:



The units in your model now balance.

[†] In units for contact frequency Vensim will cancel out people with person, recognizing from unit equivalency settings that the two point to the same concept. Current unit equivalencies are specified under **Model>Settings>Units Equiv** and can be edited to include other items.

C< The other tools are useful. The tree causes tree and the Uses Tree uses tree buttons create a representation of "causes" and "uses" trees for the selected variable. To use these tools, you need

to first select a variable. Do this by first clicking on the Move/Size button and then clicking on the variable you wish to select. Clicking on a variable selects that variable to the workbench. You can tell which variable is selected by looking at the top border of the VensimPLE window. If you select the variable Infection Rate, the top border will look like this.

Vensim:SARS_Tutorial_model_step_2.mdl Var:Infection Rate File Edit View Layout Model Options Windows Help

Having selected Infection Rate, clicking on the two "causes" and "uses" buttons in sequence gives you:



t Č The tool identifies all the feedback loops in which the selected variable is a member, and the

Document button creates a documented listing of the equations in your model.

V. Simulating Your Model

VensimPLE also has tools to help you analyze the behavior of your model. Before doing this, however, you must actually simulate the model so you have some behavior to analyze.

To run a simulation, you first need to choose a name for this particular model run. It is helpful to choose names that suggest some idea of what is being tested rather than using names like SIM1, SIM2, etc. Since this is the base case run for your model, you might choose to call the run

BASE.^{*} The name of the simulation is entered in the white box in the analysis tool bar. The default name for any simulation run is **Current**. Change this to **Base**.

To run a simulation, click the ^{simulate} button and your model will start simulating.

 \triangleright

Once the simulation run is completed, you can look at the results of your simulation. VensimPLE provides many tools with which to view simulation output. The most basic of these

is the graph. To create a graph of the **Cumulative Reported Cases**, first click on the ^{Move/Stee} tool and then click on the desired variable.

 \ge

To see a strip graph, click on the Graph button in the left toolbar. You will then see the output of your model, compared against the data. The behavior of your model will depend on the parameters you have chosen. For example, one set of parameter values and initial conditions generated the following graph:



^{*} Advanced Tip: VensimPLE also offers you the choice of two numerical integration methods, Euler and Runge-Kutta 4. Runge-Kutta 4 is a more accurate simulation method, but it is also more computationally intensive. Generally, it is better to use the Euler method and change only if you believe you are seeing integration error. Read *Business Dynamics*, Appendix A, for further details.

Besides the graph, VensimPLE provides many other ways

to examine simulation output. The substant button displays a strip graph of the currently selected variable, along with graphs of all the variables that determine the selected variable (the causes). Clicking this button gives you:



R

VensimPLE also can present the output in the form of a table rather than a graph. To see a table

simply click on the Table button.

Having examined the output of this simulation, you may wish to run additional simulations under different assumptions. For example, what would happen if you cut the contact frequency in half?

One way to do this is simply to change the model equation in the variable's equation box. This is time-consuming and error-prone, however, since you must remember to go back and change the parameter back to its original value before testing another assumption. If you change a variable's formulation in its equation box, it remains as you specify until you change it again. So, if you want to alter a variable's value only once, to observe its effect on the simulation, and then have the variable revert to its original value, you can use the Parameter Changes button, accessible on the analysis tool bar.

Test the effect of a change in the **Contact Frequency** by clicking the ^{sim Setup} button. Your screen should now look like this:



To change the contact frequency for this simulation, click on **Contact Frequency** and its current value will appear in a box. Type in a smaller value (such as a 50% reduction) and hit return. Before simulating, make sure you change the name of the simulation so that you can compare the two different runs. Select a name that helps describe the changes you made, for example, "Low Contact Frequency."

To run the simulation with your new value for the contact frequency, just click on the ^{simulate} button. Note that you have changed the contact frequency for that run only, and have not changed it in the underlying model equations.

Now when you select any of the model output tools, they show the results from both simulations (along with the data). For example, the graph tool displays:



If you do not wish to see the previous (base) run displayed with the new simulation run, then

click on the **Control Panel**. Click on the **Datasets** tab and the dialog box will display the three data sets you have created so far:

Control Panel	
Variable Time Axis Scaling Available - Info	Datasets Graphs Loaded - Info
Delete	Load From

To de-select a run, simply double-click on it. The run you de-select will now appear on the left side of the dialog, in the "available" column. It remains stored on your hard disk and can be re-loaded again any time you wish to display it. Clicking on a run in the "loaded" column will also move it to the top of the list of loaded runs so you can control the order in which runs are listed in output such as graphs.

The control panel also allows you to select a given variable (chose the **Variable** tab). Modify the horizontal axis of your graphs (the **Time Axis** tab), and create custom graphs (the **Graph** tab). See the help menu for more information on all of these features.

Vensim also offers another simulation mode, called SyntheSim, to help you analyze your model.

To activate Synthesim click on the button at the top of your screen. When you do this, SyntheSim is activated and your screen should now look like this:



All constants in your model will now appear with sliders while the other variables will have small graphs superimposed on them showing the behavior of each variable under the current slider settings. With Synthesim activated you can change any constant in your model using the sliders and Vensim will automatically re-simulate the model and provide updated output.

For small models such as this one, the response is almost instantaneous. Synthesim can be extremely useful in developing intuition as to how your model's behavior changes as its underlying parameters are adjusted. You may wish to use synthesim now to find parameter values that provide a good fit of your model output to the data for cumulative reported cases.

15.871 Introduction to System Dynamics Fall 2013

For information about citing these materials or our Terms of Use, visit: http://ocw.mit.edu/terms.