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About this Tutorial

AnyLogic™ supports different modeling techniques. This document covers System Dynamics modeling approach. There are many spheres where system dynamics simulation can be successfully applied—the range of SD applications includes business, urban, social, ecological types of systems. AnyLogic™ allows you to create complex dynamic models using standard SD graphical notation.

This tutorial will briefly take you through the process of constructing a simulation model using AnyLogic™. It is intended to introduce you to AnyLogic™ interface and many of its main features. We will create a simple illustrative example—the product life cycle model, used for forecasting sales of new products.

In the first chapter we will construct the classic Bass diffusion model. Then we will expand our model by considering some details and introducing you to some advanced features of AnyLogic™.

Note that there are several reference files available for this model representing the milestones of the editing. You can use reference files if you experience any difficulties creating a model and you would like to compare your model with the reference file. You can use the Start Page to open those examples. Start Page will appear automatically once you close the model you are editing.
1. The Product Life Cycle Model

We will create the product life cycle model. The model describes a product diffusion process. Potential customers of a product are influenced into buying the product by advertising and by word of mouth from customers – those who have already purchased the new product. Adoption of a new product driven by word of mouth is likewise an epidemic. Potential customers come into contact with customers through social interactions. A fraction of these contacts results in the purchase of the new product. The advertising causes a constant fraction of the potential customer population to adopt each time period.

1.1 Creating a new project

First, we will create a new project for your model.

► Create a new project

1. Click the New Project toolbar button. The New Project dialog appears.

2. Click the Choose Location… button and browse for the folder where you want to store your project file.

3. Specify the project name. In the Project name edit box, type Product Life Cycle.

4. Click OK.

New project is created. You see the structure diagram is displayed in the center of the workspace, the Project window is displayed in the left panel, and the Properties window—in the right one.
When working with a project, do not forget to save it by clicking Save.

1.2 Analyzing the model

Now we need to analyze the model to decide how it can be described in the system dynamics terms. We should distinguish the key variables of the model and their patterns of influence and then create stock and flow diagram of the model. When constructing stock and flow diagram, we should consider what variables should be modeled with stocks, flows or auxiliaries.

Stocks (also known as levels, accumulations, or state variables) change their value continuously over time. Flows, also known as rates, change the value of stocks. In turn, stocks in a system determine the values of flows. Intermediate concepts are known as auxiliaries and can change instantaneously.
When constructing a stock and flow diagram, consider what variables accumulate over a period of time. In our model, customer and potential customer populations are stocks and the adoption rate – a flow.

The system dynamics presentation of the model is shown in the following figure. Stocks are denoted with squares, flow with a valve, and auxiliaries with circles. Arrows denote causal dependencies in the model.

In AnyLogic™, you define stock and flow diagram using the structure diagram. There you can graphically define stocks, flows and auxiliaries. Open the structure diagram by double-clicking Main item in the workspace tree in the Project window.

1.3 Modeling customer and potential customer populations as stocks

First, we will add two stocks to model customer and potential customer populations. In AnyLogic™ a stock is represented by a variable.
Add a stock to model potential customer population

1. Click the Variable toolbar button.

2. Click the diagram where you want to place the stock.
   A new variable appears on the diagram, displayed as the blue circle.

3. Once you have placed the element onto the structure diagram, it becomes selected and its properties are displayed in the Properties window. You can adjust element properties as your model requires. To adjust properties at a later time, click the element on the structure diagram to select it and modify the properties you want.

4. Change the name of the stock. In the Properties window, type Potential_Customers in the Name edit box.

5. In the Equation section, choose Integral or Stock from the Form drop-down list. You see the stock shape is turned into the square to match the system dynamics notation.
Add a stock to model customer population

1. Add the stock in the same way. Name it Customers.

At this point, the stocks are not defined properly. Later we will define the integral functions for stocks and specify stock initial values. But we need to create the adoption flow first.
1.4 Modeling adoption as a flow

Now we will model the adoption flow, which increases the customer population, while decreasing the potential customer population. Flow is represented in AnyLogic™ by a variable. Flow value is calculated according to the specified formula.

► Create the Adoption_Rate flow

1. Click the Variable toolbar button.

2. Click the diagram where you want to place a flow.

3. Change the flow name. In the Properties window, type Adoption_Rate in the Name edit box.

4. Change the Equation Form to Formula.

We will define the flow formula later on.

1.5 Defining adoption flow influence on populations

Now we will model the flow influence on the stocks values. Stock value is calculated according to the integral function you specify. The function should be defined in the following form:

\[ <\text{inflow} \ 1> + <\text{inflow} \ 2> \ldots - <\text{outflow} \ 1> - <\text{outflow} \ 2> \ldots \]

The value of inflows i.e. flows that increase stock value, are added and the value of outflows, i.e. flows that decrease stock are subtracted from the current value of the stock.

► Define adoption outflow from potential customers pool

1. Click the Potential_Customers variable on the structure diagram.

2. In the Properties window, define the function: -Adoption_Rate. Use the function wizard to avoid typing the whole names of variables and functions in equation expressions. To open the function wizard, click at the desired position in the
\[ \frac{d(Potential\_Customers)}{dt} \] edit box, and then click \( \int \) button or press Ctrl+space. The wizard listing all model variables and predefined functions appears. Scroll to the name you want to add, or type the first letters of the name until it becomes visible in the list. Double-click the name to insert it into the equation expression.

Define adoption inflow to customers pool

1. Do it using the same approach. Enter Adoption\_Rate formula.

1.6 Adding constants

Now we will define constants of our model. In AnyLogic\textsuperscript{TM} you define a constant by creating a \textit{parameter}. 
Define a constant representing total population

1. In the Project window, double-click the Main class item.

2. In the Properties window, click the New Parameter button. In the Parameter dialog box opened, set up the parameter properties.

3. Change the name of the constant. Type Total_Population in the Name edit box.

4. In the Default value edit box, type 100000. This will be the total population in our model.

5. You may enter the short description of the parameter in the Description edit box. Type the text that may be helpful to explain the constant to someone who are not familiar with the model.

You see new parameter is added to the Parameters table.
In this model the volume of advertising and the probability that a potential customer will adopt as the result of exposure to a given amount of advertising are assumed to be constant each period. So, we will add a constant to model the advertising effectiveness—the fractional adoption rate from advertising.

► **Define a constant representing advertising effectiveness**

1. Define a constant in the similar way. Name it **Advertising_Effectiveness**.

2. Set the value to **0.011**.

The rate, with which potential customers come into contact with customers, is assumed to be constant. So, we will define a constant to represent contact rate.

► **Define the Contact_Rate constant**

1. Define the constant in the same way. Enter the name: **Contact_Rate**.

2. Assume a contact rate of 100 per person per year. In the Default value, type **100**.
Define one more constant to specify the adoption fraction—the proportion of contacts that are sufficiently persuasive to induce the potential customer to purchase the product.

Define the Adoption_Fraction constant

1. Name the constant Adoption_Fraction.
2. Set the value to 0.015.

1.7 Defining initial values of stocks

Now we are ready to specify the initial values of stocks.

Define the initial number of customers

1. On the structure diagram, click the Customers stock.
2. The initial number of product customers is zero. In the Properties window, type 0 in the Initial value edit box.

Define the initial number of potential customers

1. On the structure diagram, click the Potential_Customers stock.
2. Type Total_Population in the stock’s Initial value property (you may use the function wizard).

Now stocks definition is finished.

![Diagram of stock equations]

### 1.8 Adding auxiliaries

We need to add two auxiliaries representing adoptions resulting from word of mouth and adoptions resulting from advertising.

► **Create the Adoption_From_Advertising auxiliary**

1. Click the Variable toolbar button.
2. Click the diagram where you want an auxiliary variable created.
3. In the Properties window, change the Name to Adoption_From_Advertising.
4. Change the Equation type to Formula.
5. Define the formula expression:
   
   ```
   Advertising_Effectiveness*Potential_Customers
   ```
Create the **Adoption_From_Word_Of_Mouth** auxiliary

1. Do it in the same way except name the auxiliary **Adoption_From_Word_Of_Mouth** and specify the following formula:
   \[
   \text{Contact Rate} \times \text{Adoption Fraction} \times \text{Potential Customers} \times \text{Customers} / \text{Total Population}
   \]

1.9 **Defining the adoption rate formula**

Now we need to formulate the adoption rate. The two sources of adoption are assumed to be independent. Thus, the total adoption rate is the sum of adoptions resulting from word of mouth driven by the population of customers and adoptions resulting from advertising.
Define the formula for the adoption rate

1. Click the Adoption_Rate variable on the structure diagram.

2. In the Properties window, specify the formula expression:
   Adoption_From_Advertising+Adoption_From_Word_Of_Mouth.

Now we have completely defined our model.

1.10 Viewing causal dependencies

You may examine the causal dependencies between stocks, flows and auxiliaries in your model. They are denoted with arrows as in standard SD notation. An arrow going from flow to stock means that this flow acts as inflow for this stock. An arrow going from stock to flow means that this flow acts as outflow. A thin arrow going from A variable to B means that A causes to change B.

View the causal connections in the model

1. Click the Show/Hide Variable Dependencies toolbar button. You can see the arrows indicating causal dependencies appear.
You can see that our model has one balancing and one reinforcing feedback loop.

A balancing feedback loop affects the adoption rate due to advertising. The adoption rate reduces the pool of the potential customers, which in turn decreases the adoption rate.

A reinforcing loop affects the adoption rate due to word of mouth. The adoption rate increases the customer population, resulting in an increase of word of mouth, and thus the increase of the adoption rate.

You can examine the whole system of equations you have entered.

► To open the equation system view

1. In the Project window, expand the Main item, and double-click the Code item in the Main sub tree.

2. The equation system of your model is displayed in the Equations section of the window appeared. There you can edit the existing equations and add some new ones.
1.11 Configuring simulation

Model simulation has a set of specific settings. You can create several alternative model settings. A group of model settings is called an *experiment*, and experiments are displayed under the *Experiments* item in the model tree. One experiment is created by default and named *Simulation*. It is a *simulation experiment*, enabling model simulation with customized parameter values and with animation displayed.

There are also other types of experiments (*optimization, risk assessment, parameter variations experiment*), used when the model parameters play a significant role and you need to analyze how they affect the model behavior, or when you want to find optimal parameters of your model.

If we start the model, it will work infinitely. Since we want to observe only how the model behaves when the adoption process takes place, we need to stop the model when the system comes to equilibrium. The adoption process in this model lasts something over 8 years.

▸ Set the model to stop at time 8

1. In the *Project window*, click the *Simulation* experiment item.
2. On the *Additional* tab of the *Properties* window, select the *Stop at time* check box. In the edit box on the right, type 8. The model will stop after 8 model time units elapse.

You can set up the method used for solving differential equation systems. If you do not specify a particular solver, i.e. leave *Automatic* one, AnyLogic™ chooses a numerical solver automatically at run time in accordance to the behavior of the system.

▶ **Set up RK4 method for numerical integration**

1. On the simulation experiment’s *Additional* property page, choose RK4 method from the *Differential equations* combo box.
1.12 Running the model

Build your project by clicking the Build toolbar button. If there are some errors in your project, the building fails and the Output window appears listing all the errors found in your project. Double-click an error in the list to open the location of the error and fix it.

After the project is successfully built, you can start the model. Click Run to start the model. Up to this point, you worked with AnyLogic in the editor mode. Once the model is started, it switches to the viewer mode. In the viewer mode, you can control the model execution, inspect model variables, view the graphs, dynamically change parameters, etc.

1.13 Viewing the values of variables

There are several ways to view the values of variables in AnyLogic. First, variable values are displayed in Model Viewer.

► View the values of variables of the model

1. Click Run to start the model.

2. Click the Model Root Object toolbar button. The Model Viewer window is displayed. You can see the actual values of variables are displayed in the model tree.

   ![Model Viewer screenshot]

You can pause the model by clicking Pause and change the value of any variable you like by right-clicking the variable item in the model tree, choosing Modify from the popup menu and specifying new value in the opened dialog box.
The reference model for this point is Examples \ System Dynamics Tutorial Models \ Product Life Cycle 1 - Creating the model.alp.

1.14 Displaying variable changes with charts

You can also observe how the values of variables change during the simulation using charts.

1.14.1 Viewing customer and potential customer populations dynamics

Create a chart for Customers and Potential_Customers

1. Prepare the model to run by clicking the Step toolbar button.

2. Click the New Chart toolbar button. A chart window appears.

3. Select variables to be displayed on a chart. Click at the chart window and choose Chart Setup … from the popup menu. The Chart Setup dialog box appears.

4. Double-click root.Customers variable in the Variables, parameters, and datasets list to add it to the chart.
5. Double-click `root.Potential_Customers` variable to add it to the same chart.

6. Click OK.

▸ **Configure the chart**

1. Prepare the model to run by clicking the **Step** toolbar button.

2. Right-click the chart window and choose **Chart Options** … from the popup menu. Set up the chart’s time diapason in the dialog box opened:
Now restart the model by clicking Restart Model and then clicking Run. The chart displays how Potential_Customers and Customers variables change during simulation. You see classic S-shaped diffusion curves.

### 1.14.2 Examining the adoption rate

Now we will create a chart to show how the adoption rate changes in our model.
Create a chart for Adoption_Rate

1. Create a new chart in the same way you did in the previous section. Add Adoption_Rate variable to be displayed on the chart.

Restart your model by clicking Restart Model and then clicking Run. You see classic bell-shaped curve.

1.14.3 Viewing the contribution of different adoption sources

We want to see when the effect from word of mouth begins to outbalance the effect from advertising. Therefore, we need to create a chart displaying these variables and find the intersection point of their plots.

Create a chart displaying adoption from advertising and adoption from word of mouth

1. Create a new chart displaying Adoption_From_Advertising and Adoption_From_Word_Of_Mouth variables.

Restart the model by clicking Restart Model and then clicking Run. Now we can easily see that when an innovation is introduced and the customer population is zero, the only source of adoption will be advertising. The advertising effect is largest at the start of the diffusion process and steadily diminishes as the pool of potential customers is depleted.
The chart changes scales automatically to embrace the plots. The chart displays the variables changing from the beginning to the end of simulation, while we need to examine a particular time segment.

► Set up the chart to display the variable changing in specified time window only

1. Right-click at the chart and choose Chart Options… from the popup menu. The Chart Options dialog box appears. Specify the length of the time segment in the Window size edit box on the Axes page. Type 1 and click OK. Now the chart shows the plots only for the last time unit.

2. Restart the model by clicking Restart Model and then clicking Run. Scroll the chart to see the beginning of simulation. Now you can see that the plots intersect near (0.46, 11000).

The reference model for this point is Examples\System Dynamics Tutorial Models\Product Life Cycle 2 - Charts.alp.
1.15 Creating a show-bench

In this section we will create a show-bench for playing with the model by changing the values of constants (advertising effectiveness, contact rate and total population) and observing how these actions influence the model. The changes will be shown by charts and animated stock and flow diagram.

1.15.1 Creating animation diagram

To create a show-bench you need to draw it using an animation diagram.

► Create an animation

1. Click the New Animation toolbar button. In the dialog box opened, give a name to a model animation.

► Edit the animation frame

1. Set the coordinates to (0,0) by moving the frame shape. Click the animation frame rectangle and drag it so its left upper corner fits the axis-cross origin—the diagram coordinates origin. Resize the animation frame to (600,350) by dragging the handles (the coordinates of the mouse cursor are shown in the status bar).

In the same manner, you can move or resize all other shapes on the diagram.
Add a show-bench title

1. Click the Text toolbar button.

2. Click the diagram near (25,20) to place the text shape.

3. Define the text to be displayed in the text box created. On the Text page of the Properties window, type Product Life Cycle Model in the Text edit box.

4. Change the text font. In the Font section, click the Choose button and in the dialog box opened set bold Arial font of size 12.

1.15.2 Creating animated stock and flow diagram

Now we will create the animated stock and flow diagram like shown in the figure below.
First, we will draw stock and flow diagram with geometric shapes (lines, rectangles, etc.) and then we will animate the stock and flow diagram by adding indicators (charts, bar and arc indicators). Finally, we will add controls for varying the values of the model constants.

► **Add the stock and flow diagram border**

1. Click the Rectangle toolbar button.

2. Click the diagram near (230,100) and drag to (590,340).

Now we will animate the stocks defined in our model with bar indicators. The bar indicator shows how the stock is filled at the current moment relative to the specified boundaries.

► **Add a bar indicator for the Potential_Customers stock**

1. Click the Bar Indicator toolbar button.

2. Click the diagram near (270,120) to place a bar indicator.

3. Resize the indicator shape to (60,40).
4. On the Bar Indicator page of the Properties window, choose Potential_Customers from the Value to indicate combo box.

5. Set the maximum value. Type Total_Population in the Max value edit box.

6. Clear the Show scale check box.

7. Change Orientation to Horizontal.

► Add a bar indicator for the Customers stock

1. Right-click the created stock shape and choose Copy from the popup menu.

2. Right-click the diagram and choose Paste from the popup menu. New indicator shape appears on the diagram. Place it 220 points to the right of the potential customers stock.

3. Leave all properties by default except set the Customers variable as the Value to indicate.

Now we will draw an arrow to denote the flow on the diagram.

► Add an arrow to denote adoption flow

1. Click the Line toolbar button.

2. Click the diagram at the right border of potential customers stock shape to place the line’s begin point.

3. Click at the left border of customers stock shape to place the line’s end point.


5. On the Line page of the Properties window, choose Arrow as the End point style.

Now we will animate the adoption flow. Flows are best represented by arc indicators. Arc indicators display value of the associated variable within the specified range.
► Add an arc indicator to display adoption rate value

1. Click the *Arc Indicator* toolbar button.

2. Click on the center of the arrow to place the arc indicator over it.

3. Set the arc indicator to display adoption rate. On the *Arc Indicator* page of the *Properties* window, choose *Adoption_Rate* from the *Value to indicate* combo box.

4. Clear the *Show scale* check box.

5. Set the *Max value* to 40000.

► Add text labels for created indicators

1. Add new label displaying *Potential Customers* text and place it below the potential customers indicator.

2. Add *Customers* text label below the customers indicator shape.

3. Add *Adoption Rate* label below adoption rate indicator.

Add charts to the animation displaying *Adoption_From_Advertising* and *Adoption_From_Word_Of_Mouth* variables changing during simulation.

► Create a chart for *Adoption_From_Advertising* auxiliary

1. Click the *Chart Indicator* toolbar button.

2. Click diagram near (310, 240) to place a chart.

3. On the *Chart Indicator* page of the *Properties* window, choose *Adoption_From_Advertising* from the *Value to indicate* combo box.

4. Set *Window size* to 8 (so the chart will display all the simulation run).

5. Change *Max value* to 1500.
Create a chart for Adoption From Word Of Mouth auxiliary

1. Add a chart to the animation using the same approach. Place it near (460,240).
2. Choose the Adoption From Word Of Mouth variable as Value to indicate.
3. Set Window size to 8.
4. Change Max value to 400000.

Now we will draw arrows to denote causal connections in your model.

Create arrows indicating causal connections

1. Draw an arrow going from the Potential Customers indicator to the Adoption from Advertising indicator. Leave all properties by default except change the End point style to Arrow.
2. Draw an arrow going from Adoption from Advertising to Adoption Rate.
3. Draw an arrow going from Adoption from Word of Mouth to Adoption Rate.
4. Draw an arrow going from Customers to Adoption from Word of Mouth.

Now we have completely defined the animated stock and flow diagram. Before running the model, we will set the real time mode to control the execution speed and, consequently, animation speed. In real time mode, the model is executed regarding the physical time.

Set the real time execution mode

1. In the Project window, click the current simulation experiment item.
2. On the General page of the Properties window, set the Simulation speed to Real time mode.
3. Specify the model execution speed, i.e., how many model time units will be executed in one second. In the Model time units per second edit box, type 2.

Click Run to start the model. Having started the model, you will see the animation window.
To get a better view at run time, you can set the anti-aliasing.

► **Set the anti-aliasing mode**

1. Click *Animation settings…* toolbar button. In a dialog box opened, select the *Enable anti-aliasing* option.

To adjust the execution speed, use *Decrease model speed* and *Increase model speed* toolbar buttons.
The reference model for this point is Examples \ System Dynamics Tutorial Models \ Product Life Cycle 3 - Animated stock and flow diagram.alp.

### 1.15.3 Adding controls

You can add controls to your animation for controlling variable values during the simulation. We will add sliders for the total population, contact rate and advertising effectiveness.

▸ Add text labels to indicate the total number of people

1. Add a text label. Set **Text** to: **Total Population:** .

2. Add a text label to the right to display the value of **Total_Population** variable at run time. Choose **Total_Population** from the combo box below the **Text** edit box located on the **Text** properties page.

▸ Add a slider to vary total population value

1. Click the **Slider** toolbar button.
2. Click the diagram below the created labels.

3. Resize the slider shape to (180,20).

4. On the General page of the Properties window, type:
   
   ```java
   getTime() == 0.0
   ```
   
in the Visible edit box.
   
   This condition will hide the slider at the model runtime. Thus you will be allowed to change the total population only before you run the model.

5. On the Slider page of the Properties window, choose the Variable name to control with the slider: `Total_Population`.

6. Set the Min value to 100 000.

7. Set the Max value to 10 000 000.

8. Specify the Event handling code:
   
   ```java
   Potential_Customers = Total_Population;
   ```
   
   This code will reinitialize the number of potential customers when you change the total population with a slider.

9. **Add text labels to show the slider range**

   1. Add 100 000 text label to the left of the slider.
   
   2. Add 10 000 000 text label to the right of the slider.
   
   3. For both labels, on the General page of the Properties window, type:
      
      ```java
      getTime() == 0.0
      ```
      
in the Visible edit box.
      
      This condition will hide labels at the model runtime.

10. **Create the same control group for changing contact rate**

    1. You may copy the created control group (select the slider and the labels by clicking on them with Shift pressed).
    
    2. Set `Contact_Rate` as the slider variable. Set the Min value to 30 and the Max value to 300.
3. Set text labels to display respectively **Contact Rate**: text and the value of **Contact_Rate** variable.

4. Set the slider range labels to display respectively 30 and 300.

► **Create the control group for advertising effectiveness**

1. Set **Advertising_Effectiveness** as the slider variable. Set the **Min value** to 0 and the **Max value** to 0.05.

2. Set text labels to display respectively **Advertising Effectiveness**: text and the value of **Advertising_Effectiveness** variable.

3. Set the slider range labels to display 0 and 0.05.

Now you can test how controls work.

► **Play with the sliders**

1. Set your model at the beginning of simulation by clicking the **Step** toolbar button.

2. Change the parameter value with the slider.

3. Start the model by clicking **Run** and see how the model behavior has changed.
The reference model for this point is `Examples\System Dynamics Tutorial Models\Product Life Cycle 4 - Controls.alp`.

This model demonstrated the basics of creating System Dynamics models in AnyLogic™. Now we are ready to create more advanced model.
2. Expanding the Product Life Cycle Model

In this chapter we will expand our model by considering some details and introducing you to some advanced features of AnyLogic™ useful in creating system dynamics models. The expanded model may help you to better plan the entry strategy, target the right consumer and anticipate demand so as to have an efficient and effective promotion strategy.

2.1 Adding replacement purchases logic

The model we have created does not capture situations where the product is consumed, discarded, or upgraded, all of which lead to repeat purchases. We will model repeat purchase behavior by assuming that customers move back into the population of potential customers when their first unit is discarded or consumed.

2.1.1 Modeling the product discard rate

First, we will define a constant representing the average life time of product.

► Define the Average_Product_Life constant

1. Assume that the average duration of active use of our product is 2 years. Type 2 as the Default value.
People move back from the customer population to the pool of potential customers when the product they have purchased is discarded or consumed. So, the discard flow is nothing else but the adoption flow delayed on the average life time of the product.

► Create the discard flow

1. Place the flow above the adoption flow shape.
2. Name it Discard_Rate.
3. Set the following Formula expression:
   \[ \text{delay(Adoption Rate, Average Product Life, 0)} \]

   The \text{delay()} function implements the time delay and has the following notation:
   \[ \text{delay(<variable>, <delay value>, <initial value>)} \]

   In our case, function reproduces Adoption Rate delayed on the Average Product Life value. The discard rate is null until the time of use of the first purchased products elapses.

► Define discard outflow from customers pool

1. Modify the formula of the Customers stock. Since now the discard flow decreases the stock, the formula should be: Adoption Rate - Discard Rate.

► Define discard inflow to potential customers pool

1. Modify the formula of the Potential_Customers stock. Since now the discard flow increases the stock, the formula should be: -Adoption Rate + Discard Rate.

Now we have finished modeling the product replacement purchases. You may check how the delay function works. Click Run to start the model.

► Create a timed chart displaying Adoption Rate and Discard Rate

1. You can simply add the Discard_Rate variable to be displayed on the chart of Adoption_Rate.
Restart the model by clicking Restart Model and then clicking Run. We can see that rate curves look exactly how we expected—the discard rate is actually the adoption rate delayed by 2 years—the lifetime of the product.

View the population dynamics using another chart.

Now, instead of falling to zero, the potential customer population is constantly replenished as customers discard the product and reenter the market. The adoption rate rises, peaks, and falls to a rate that depends on the average life of the product and the parameters determining
the adoption rate. Discards mean there is always some fraction of the population in the potential customer pool.

2.1.2 Modifying the animation

Since the model has changed, we need to alter the model animation and animate the discard rate as well. The animation should look as in the following figure.

First, we will draw an arrow to denote the flow.

▶ Denote the discard rate on animation

1. Resize the stock and flow diagram border to be 330 points high.

2. Click the Polyline toolbar button.

3. Click the diagram at the top of the customers indicator.
4. Place two more polyline points by clicking the diagram 70 points above this point and then clicking 220 points to the left.

5. Double-click at the top of the potential customers indicator to add polyline’s end point.


7. On the Polyline page, choose Arrow as the End point style.

Now we will add an arc indicator to display the current value of the discard flow.

► Add an arc indicator displaying the rate value

1. Copy the arc indicator displaying adoption rate and paste it over the center of the created polyline. Set Discard_Rate as the Value to indicate.

► Add a text label for created flow

1. Add Discard Rate text label below the created indicator.

► Create the control group for average product life

1. Set Average_Product_Life as the slider variable. Set the Min value to 0.5 and the Max value to 10.

2. Set text labels to display respectively Average Product Life: text and the value of Average_Product_Life variable.

3. Set the slider range labels to display 0.5 and 10.

Now the model animation is up-to-date. Click Run to start the model and observe the model behavior using the animated stock and flow diagram.

⚠️ The reference model for this point is Examples \ System Dynamics Tutorial Models \ Product Life Cycle 5 - Replacement purchases.alp.
2.2 Modeling the demand cycle

The adoption fraction in our model is constant each period. Actually it changes in a complex way since the demand on our product follows the cycle of the seasons. The peak of the demand is in summer while in winter the product is in little demand. There is also a little peak in customer activity before the New Year holiday. We want to model the demand cycle and its affect on the adoption fraction in our model.

2.2.1 Adding experimental data to model

Assume that we have experimental data how the average demand on the product changes during the year. We will use a lookup table to add this data to our model. Lookup table is a function defined in the table form. It returns tabulated values for defined argument values. If the function argument does not correspond to any of the tabulated values, lookup table computes a value based on interpolation.

Model the demand curve with a lookup table

1. Click the New Lookup Table toolbar button. In the dialog box opened, define the lookup’s Name: demand.

2. On the General page of the Properties window, enter the function Data. Click the empty Argument cell and enter a new argument of the function. Then click the adjacent Function cell and enter the function value for this argument. Define the function values as in the following figure:
3. Set the *Linear interpolation*, where the data takes a straight line between data points.

4. Select the *Use nearest valid argument* option for out-of-range arguments.

5. Click the *Show Scatter…* button. In the dialog appeared you can see how the demand curve looks.
2.2.2 Formulating the adoption fraction

Now we want to model how the adoption fraction depends on the current demand on the product. Therefore we will define a custom mathematical function and replace the Adoption_Fraction parameter with the auxiliary, which value is calculated according to this function.

► Define a mathematical function evaluating the adoption fraction

1. Click the New mathematical function toolbar button. In the dialog opened, specify adoptFraction as the Name of the function.

2. Specify that the function returns the real value. In the Properties window, leave the default real type of the returned value.

3. Our function should have one argument to pass the current time value to the function. In the Arguments table, add argument of Type real named time.
4. Enter the function expression. In the *Expression*, type:

\[ \text{demand}((\text{time}-\text{floor}(\text{time}))*12+1)/200.0 \]

This expression calculates the number of the current month and passes it to the `demand` lookup. The lookup returns the demand value for the current month. Finally, to obtain the adoption fraction value, the demand value is divided on the conversion factor.

The `floor()` is AnyLogic™ predefined function. You can use frequently used functions (sin, cos, exp, etc.) in your expressions. Entering expressions, you can use the function wizard, where predefined functions, function arguments and lookups are listed as well as variables.

Please refer to *User’s Manual* or *Class Reference* (see the Func class methods) for the detailed description of functions and its parameters. To invoke AnyLogic™ *User’s Manual* or *Class Reference*, choose these items from the Help menu.

Finally, we will replace the adoption fraction constant with the auxiliary evaluating its value with the created function.

**Delete the Adoption_Fraction parameter**

1. In the *Project window*, click the *Main* item.
2. In the Properties window, select the Adoption_Fraction parameter in the Parameters table, and then click the Delete button.

► Create the Adoption_Fraction auxiliary

1. Set the Formula: adoptFraction(t). Thus, the auxiliary value will be computed by our mathematical function. The function takes one argument, t. Typing t in equations we refer to the current model time.

Set model to stop at time 25 and click Run to start the model. You can see that now the behavior of a model deviates above and below an equilibrium point since the adoption rate and the discard rate oscillate.
The reference model for this point is Examples\ System Dynamics Tutorial Models\ Product Life Cycle 6 - Demand cycle.alp.

2.3 Modeling a promotion strategy

At this point, advertising effectiveness in our model is assumed to be constant each period. Actually, it depends on the current advertising expenditures. We want to improve our model to be able to manage the promotion expenditures. Changing the monthly promotion expenditures we will affect the advertising effectiveness.

2.3.1 Modeling advertising expenditures

▸ Add a constant for the monthly expenditures

1. Add the Monthly_Expenditures parameter.

2. Specify the parameter’s Default value: 1100.
Replace Advertising_Effectiveness constant with an auxiliary

1. Delete Advertising_Effectiveness parameter.

2. Create Advertising_Effectiveness variable with Formula:
   Monthly_Expenditures/10000.0. We assume this is how the advertising effectiveness depends on the current promotion expenditures.

We want to collect statistics on the total expenditures of our company. We will implement this by defining a variable, keeping data about how many money was appropriated for the product promotion. Every month we will update the Total_Expenditures variable, adding the value of expenditures for the upcoming month. We will implement this by creating a monthly timer.

Add an auxiliary for the total expenditures

1. Add the Total_Expenditures variable.

2. Leave the default No Equation option. Specify the Initial value 0.0.
Create a timer to update Total_Expenditures

1. Click the Chart Timer toolbar button.
2. Click on the structure diagram to place the timer.
3. In the Properties window, set monthlyTimer as the Name of the timer.
4. Set up timer to expire monthly. Choose the Cyclic option. Since one model time unit in our model corresponds to one year, $1.0/12.0$ corresponds to one month. Specify $1.0/12.0$ as Timeout. Set timer to Expire at startup.
5. In the Expiry action, type:
   
   ```
   Total_Expenditures += Monthly_Expenditures;
   ```
   
   This code will be executed each time the timer’s timeout is elapsed. It collects statistics on the total expenditures, namely it adds the value of advertising expenditures planned on the upcoming month to the Total_Expenditures.
2.3.2  Modeling a promotion plan

Since advertising plays significant role only at the start of the diffusion process, we want to stop advertising at some moment of time, say, after 3 years. Thus we will save money aimlessly spent on advertising, since only adoption from word of mouth determines the market saturation by that time.

► Add a constant for the switch time

1. Add the Switch_Time parameter.

2. Specify the parameter’s Default value: 3.0.

Now we will define model behavior visually with a statechart.
Create a statechart to model promotion strategy

1. Click the Statechart toolbar button and click the diagram to create a new statechart. The statechart shape appears on the diagram. Double-click it to open the statechart diagram. Draw the following statechart:

![Statechart Diagram]

2. Add a state. Click State and click the statechart diagram to place the first state. Press F2 and rename it to with advertising.

3. Make this state initial. Therefore, add initial state pointer going into it. Click Initial State Pointer, then click the diagram above the upper state and then click on the state border.

4. Add one more state below the created one. Name it without advertising. We need to stop the promotion, when statechart comes to this state. Therefore, in the Entry action property, type Monthly_Expenditures=0.0;.
5. Add a transition going from the with advertising state to the without advertising state. Set up that this transition will be taken after Switch_Time timeout. Therefore, choose After timeout from the Fire drop-down list and type Switch_Time in the Timeout property.

Now when the statechart is in the initial with advertising state, company’s advertising expenditures are defined by the Monthly_Expenditures value. Once the statechart exits this state at the Switch_Time moment, company stops advertising.

Click Run to start the model and see that now the promotion company lasts only 3 years.

⚠️ The reference model for this point is Examples\System Dynamics Tutorial Models\Product Life Cycle 7 - Promotion strategy.alp.
2.4 Optimizing the product launch strategy

The marketing strategy in the current model is very simple: at the specified moment of time company stops advertising the product. We want to find an optimal marketing plan to reach the required number of customers to the specified moment of time with minimal advertising expenditures. We can solve this problem by using AnyLogic™ optimization, where elected model parameters are systematically adjusted to minimize or maximize the objective function.

2.4.1 Checking the market saturation

First, we will define a constant representing the required market saturation threshold, say 80 per cents from the total population.

► Add the Expected_Saturation constant

1. Specify the Default value: Total_Population*0.8.

Now we will add a constant defining the moment of time when the required number of customers should be reached.

► Add the Saturation_Time constant

1. Specify the Default value: 1.5.

We will model market saturation check visually with a statechart.
**Alter the statechart to model marketing strategy**

1. Double-click the `statechart` item in the *Model* tree to open the statechart diagram. Modify the statechart so it will look as in the following figure:

![Statechart Diagram](image)

2. Add a composite state containing the existing two states.

3. Add an initial state pointer going into the composite state.

4. Add an internal transition to the composite state. Set up the transition to perform the market saturation check after `Saturation_Time` timeout. Therefore, choose *After timeout* from the *Fire* drop-down list and type `Saturation_Time` in the *Timeout* property. In the *Guard*, type: `Customers<=Expected_Saturation`. The *Guard* condition checks, whether the required number of customers is reached. If *Guard* is true, the transition is triggered and the *Action* code is executed. In the *Action*, type: `Total_Expenditures=50000;`. We increase the `Total_Expenditures` value to indicate that our requirement is not met.
2.4.2 Configuring optimization

Now the model definition is completed, we can set up the optimization options.

► Create new optimization experiment

1. Click the New Experiment toolbar button. In a dialog box opened, specify the experiment name and choose the Optimization experiment type.

2. Set this experiment as current. In the Project window, right-click the experiment item and choose Set as Current from the popup menu.

3. Configure the created experiment. On the Additional page of the Properties window set model to Stop at time 1.6.

4. Click the Settings… button and in the dialog box opened set Parameter precision to 0.00001 and Maximum iterations number to 1500.
5. We want to minimize money spent on the product promotion. On the General page of the Properties window, choose Total_Expenditures as the Objective function and check that the Minimize check box is selected.

We will optimize the parameters Monthly_Expenditures and Switch_Time.

▶ Set up parameters to optimize

1. Add Switch_Time optimization parameter. In the Parameters table on the General page of the Properties window, click the Parameter cell and choose Switch_Time parameter from the combo box. Leave default parameter properties except set Max value to 1.5 and Suggested value to 1.0.

During optimization, the parameter values used in the model will be systematically adjusted to find the smallest value of the `Total_Expenditures` variable, set as the objective function.

### 2.4.3 Running optimization

The model is now ready to optimize. Click Run to run the optimization. AnyLogic runs the model 1500 times, adjusting the values of `Monthly_Expenditures` and `Switch_Time`. A summary of the optimization statistics is displayed in the `Optimization` window.
When the optimization process finishes, the **Optimization** window shows that **Best objective found** is 4675.26. The optimization eventually converges on new parameter values of $\text{Switch Time} = 0.24852$ and $\text{Monthly Expenditures} = 1558.42$.

Now we can update the model with the optimized values of **Switch Time** and **Monthly Expenditures**. Save the resulting parameter values in the **Simulation** experiment to adopt the found solution in the model.

► **Adopt optimization results**

1. Click the **Store best solution in simulation** button. In the dialog box opened, choose the simulation experiment to which you will copy optimization results. Leave the default **Simulation** experiment and click **OK**.

Set **Simulation** experiment as current and **Run** the model with the optimized parameters to confirm that the required number of customers is reached by the **Saturation Time**.

Now you have planned your entry strategy so as to have an efficient and effective promotion.

÷ The reference model for this point is **Examples \ System Dynamics Tutorial Models \ Product Life Cycle 8 - Optimizing entry strategy.alp**.
3. Conclusion

This tutorial has shown you the basic steps of creating system dynamics models. In case you need to extend your model and go beyond pure system dynamics modeling, you can seamlessly use any other AnyLogic™ modeling techniques in your model. Only in AnyLogic™ you can combine System Dynamics together with Agent-based modeling to model systems with complex behavior that can’t be implemented as pure System Dynamics models. For more information about the modeling techniques and ways AnyLogic™ supports, please refer to User’s Manual.

You can find some System Dynamics models in AnyLogic™ examples pack, including:

- Predator Prey
- Population
- Population With Arrays
- Bass Diffusion
- Lorenz Weather Model
- Patient Flow SD

These models can serve as a good starting point for finding ideas how to approach your problem in SD style.