Software Training Guide

ReliaSoft's
BlockSim

Born of ReliaSoft ingenuity,
Bred to set new standards…

RS

***ReliaSoft* Corporation**
ReliaSoft Plaza
115 South Sherwood Village Drive
Tucson, AZ 85710
USA
+1.520.886.0366
Support@ReliaSoft.com
http://BlockSim.ReliaSoft.com

Printed in the United States of America
10 9 8 7 6 5

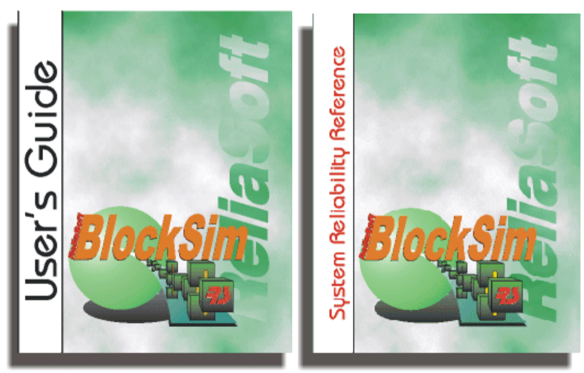
1 BlockSim Training Guide

1.1 About this Training Guide

This training guide is intended to provide you with many examples of BlockSim. This training guide begins with step-by-step examples and then proceeds into more advanced examples and questions. At any time during the training, please feel free to ask the instructor(s) any questions you might have.

1.2 BlockSim Documentation

Like all of ReliaSoft's standard software products, BlockSim is shipped with detailed printed documentation on the product (*BlockSim User's Guide*) and the underlying principles and theory (*ReliaSoft's System Reliability Reference*). This training guide is intended to be a supplement to those references.



1.3 Contacting ReliaSoft

ReliaSoft can be reached at:

ReliaSoft Corporation
ReliaSoft Plaza
115 South Sherwood Village Drive
Tucson, AZ 85710 USA
Phone: +1.520.886.0366
Fax: +1.520.886.0399
E-mail: Support@ReliaSoft.com

For up-to-date product information, visit our Web site at:
http://BlockSim.ReliaSoft.com

2 Features Summary

The examples in this training guide have been designed to introduce you to the features available in BlockSim. This section presents a brief summary of these features. If you are already familiar with BlockSim's features, you can proceed to Chapter 3, First Steps.

2.1 Using BlockSim

BlockSim allows you to analyze any process or product to obtain exact system reliability results (including system reliabilities, mean times, failure rates, etc.), to calculate the optimum scenario to meet system reliability goals and to obtain maintainability/availability results through simulation. BlockSim's blocks can be defined with the reliability characteristics of each component of the process or product. You can then configure these blocks into a reliability block diagram (RBD) that represents the reliability-wise configuration of the system and analyze the diagram in order to determine the reliability function (cumulative density function or *cdf*) of the entire system. This analysis can be used to make statistical calculations and create plots, to perform "what-if" analyses, to determine the optimization of system reliability to meet time and cost goals that you specify and to perform maintainability/availability and reliability simulations.

2.2 Intuitive Work Environment

BlockSim's interface is an intelligent, flexible and completely integrated work center. The work environment is designed around the Multiple Document Interface (MDI) and BlockSim's Project Explorer. These tools allow you to display and manage the diagrams, spreadsheets, plot sheets, templates and FRED report sheets you will create and use in BlockSim. From within BlockSim's MDI, you can use BlockSim's integrated calculation and plotting tools to analyze your diagrams, make system reliability calculations, create and modify plots and graphics and calculate the optimum reliability scenario. You can also easily interact with other ReliaSoft and Windows applications. This is all included in one comprehensive, easy-to-use package.

2.3 Easy to Use

ReliaSoft's BlockSim was designed and built for Microsoft Windows and takes full advantage of the best features Windows has to offer. Using the familiar Windows interface, as well as the examples and help provided, you can be up and running from the moment the application is installed. You can be productive immediately, without the normal down-time you would expect when learning a new software application. But making it easy does not mean we made it less powerful. BlockSim comes packed with advanced features that you will find indispensable and you will learn and master them as you explore the software. Complete Windows on-line help is also provided.

2.4 Blocks and Templates

BlockSim's blocks are the building blocks with which you will create complex reliability block diagrams. You start with BlockSim's templates, which contain pre-defined sets of re-usable blocks. BlockSim provides a gallery of templates to get you started and provides you with the flexibility to manage these collections of building blocks to meet your specific needs. You can customize individual blocks with the failure, repair, maintenance and reliability optimization characteristics for each component in your system. You can also define BlockSim's blocks with the included failure/repair distributions, define your own distribution or specify a fixed reliability value for the component at a specified point in time or without respect to time.

2.5 Available Life Distributions

The life distributions available within BlockSim to define the failure and repair characteristics of system components include the Weibull, Exponential, Normal, Lognormal and Mixed Weibull (with two, three or four subpopulations) distributions. BlockSim also provides the capability to compute the appropriate distribution and parameters for a component using ReliaSoft's Weibull++ life data analysis software.

2.5.1 Integration with Weibull++

The capabilities of ReliaSoft's suite of reliability engineering software products have been designed to complement one another. With BlockSim, we introduce a new level of integration. You can use an existing *.wdf file created in ReliaSoft's Weibull++ software to define the failure or repair characteristics of a BlockSim block and even use Weibull++ to compute the distribution and parameters “on the fly” from within BlockSim. ReliaSoft's Weibull++ must be installed on your computer in order to utilize this option. Contact ReliaSoft for information on obtaining this powerful life data analysis application.

2.6 System Reliability Block Diagrams

Simple drag-and-drop functionality allows you to drag blocks from a template into a diagram sheet and configure those blocks to create simple or complex reliability block diagrams (RBDs). With BlockSim, you can diagram systems with series, parallel and “k-out-of-n” reliability-wise configurations, as well as complex combinations of those configuration types. You can also customize the size and shape of component blocks, connecting lines, diagram background, graphics and text.

2.6.1 Template Blocks

Template blocks are the main building blocks of your reliability block diagrams. You can define these re-usable blocks with the failure, repair, maintenance and reliability optimization characteristics of the components they represent. BlockSim's template blocks allow you to define the characteristics of a component once and use the same block in many RBDs to save time.

2.6.2 Node Blocks

Node blocks are another type of block that can be used in the reliability block diagrams you create. Node blocks act as switches through which RBD paths move. You can specify how many paths leading into a node must be operational in order for the node to function. You can also define the properties of the node itself, including whether it can fail and its failure distribution.

2.6.3 Subdiagram Blocks

In addition to the complex reliability-wise configurations supported by BlockSim's diagram sheets, you can also link diagrams by using existing RBDs as components in other diagrams. BlockSim's Block As Diagram option creates a block which represents the reliability characteristics of an existing BlockSim diagram. This block serves as a subdiagram to the current diagram. This subdiagram block can then be placed into any diagram as a component. You can even place these subdiagram blocks into a template so that they can easily be re-used in other diagrams.

2.7 Unparalleled Plots and Graphs

BlockSim offers unparalleled plots and graphics capabilities. With the click of a button, you can create Reliability vs. Time, Probability of Failure vs. Time, *pdf*, Failure Rate vs. Time, Static Reliability Importance, Reliability Importance vs. Time and Availability vs. Time plots based on system RBDs. You also have the flexibility to create a variety of plots and graphs with the Chart Wizard in BlockSim's spreadsheets. With the Chart Designer, any of these graphs can be extensively customized to meet your particular needs. All BlockSim plots can be saved as Windows metafile (*.wmf) graphics that can be used in other applications.

2.8 Quick Calculation Pad

ReliaSoft's Quick Calculation Pad (QCP) provides a quick, easy and accurate way for you to obtain exact results for the most frequently asked reliability questions. From standard probability and mean time calculations, to optimization algorithms, it is all possible using the QCP. All QCP results can be displayed and manipulated in the Results Panel and flexible spreadsheets.

2.8.1 Reliability Metrics

BlockSim's powerful analysis engines analyze the diagrams you create in order to obtain the complete mathematical system reliability function (or cumulative density function, *cdf*). You can use that real system *cdf* and not just a simple simulation, to obtain exact reliability results from BlockSim's Quick Calculation Pad (QCP). Calculations include reliability, probability of failure, conditional reliability, conditional probability of failure, failure rate, warranty time, B(X) information and mean time.

2.8.2 “What-If” Analyses

In addition to providing quick, easy reliability calculations for the system diagrams you create, BlockSim provides you with the flexibility to manipulate a diagram in order to perform “what-if” analyses. BlockSim allows you to mark a component (or components) as inactive (*i.e.* failed, off or absent from the system) and use the QCP to determine reliability metrics of the system under those hypothetical conditions.

2.8.3 Optimize System Reliability

You can also use BlockSim's QCP to calculate the best way to optimize system reliability based on time and cost goals that you provide. You can specify system reliability and time goals and select components to be considered when calculating the optimum scenario for meeting those goals. Based on your specification of the feasibility (or cost) of improving the reliability of each individual component, BlockSim calculates an optimization algorithm that returns the optimum scenario for increasing component reliability in order to achieve a system reliability goal. You can use BlockSim’s feasibility functions or specify your own customized functions to describe the cost feasibility for increasing the reliability of a specific component.

2.9 Reliability and Maintainability/Availability Simulations

In addition to calculating the exact mathematical system reliability function for your system diagrams, BlockSim also provides a simulation utility. With this tool, you can perform simulations based on a linked RBD to estimate the system reliability (and failure rate) or to obtain system maintainability/availability results for a specified period of time.

2.10 Spreadsheets

With BlockSim's spreadsheets, you can unleash endless possibilities. These spreadsheets can be used just as you would use an Excel or Quattro spreadsheet with complete in-cell formula support, cell references and over 140 built-in functions. Use this flexibility, coupled with all of the powerful data analysis capabilities of BlockSim, to perform calculations, create plots and graphs and prepare presentations of your analyses. The capabilities of BlockSim's spreadsheets are limited only by your imagination and creativity.

2.11 Report Work Center

ReliaSoft's Report Work Center (RWC) allows you to streamline and automate report creation. Comprised of two pages, the Editor and the Template, the RWC works both as a traditional word processing utility and also as a report generator. Using the Function Wizard, you can create forms with fields in the RWC Template page that are filled in with the correct data in the Editor page. The RWC also includes a Web Publish option that converts the Report Work Center document into HTML and allows you to preview the Internet/intranet-ready document.

2.12 Function Wizard

Use ReliaSoft's Function Wizard in conjunction with BlockSim's spreadsheets and Report Work Center to generate a variety of calculated results. The Function Wizard returns results based on a linked RBD. Results include tables of failure rates given a time range, mean times of the system, reliability given time and more. Use these results to create graphs and reports to present your analyses.

2.13 Graph File Manager

The appearance of BlockSim blocks can be customized with bitmap graphics. Select a bitmap from the graphics library to be displayed on your blocks or use your own bitmap (*.bmp) files. Organize and preview all of your bitmap graphics using the Graph File Manager. Preview the graphics within a particular directory before choosing one to be displayed on the selected block.

2.14 Customize the Application

BlockSim provides a User Setup that allows you to customize the application to meet your particular needs. The User Setup allows you to configure the software to suit the way you and your company work. Customize the way the software works or use the preferences pre-set by ReliaSoft. You can set the entire look and feel of the software. For example, you can determine the decimal place accuracy you would like to see, for up to fifteen decimal places. You can also decide whether results are displayed in percent or in decimal format.

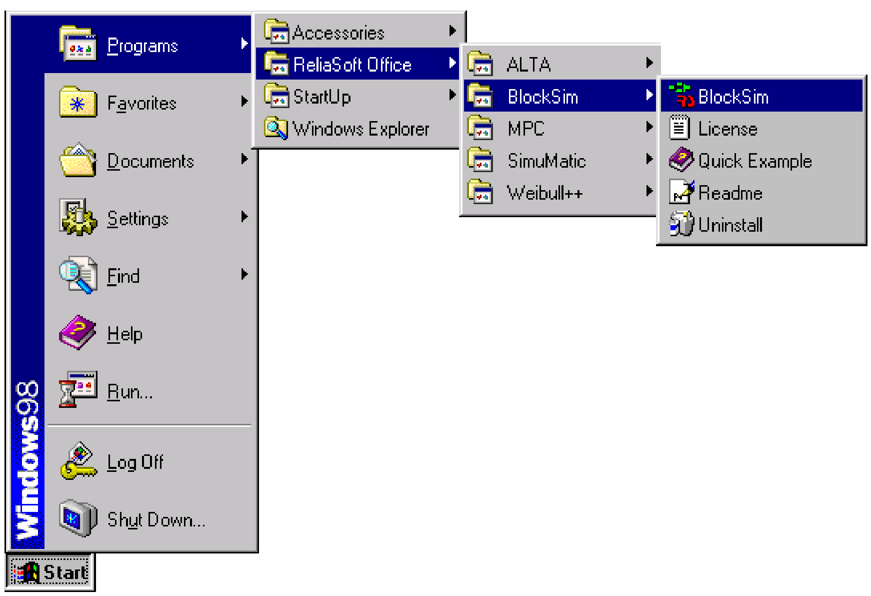
2.15 A Note on Calculations

The results generated by BlockSim's analysis tools do not specify the units (*e.g.* hours, miles, etc.) for the values returned. It must be understood that the units for the results are the same as the units for the data inputs on which results are based. For this reason, BlockSim requires a uniformity of units among the property definitions of blocks in diagram sheets and required inputs for calculations. For example, all time values in a diagram sheet and in the analysis tools used to generate results based on that diagram must be defined with the same units.

3 First Steps

3.1 Starting BlockSim

BlockSim is a 32-bit application that has been designed to work with Windows 95, Windows 98, Windows Me, Windows NT and Windows 2000. To start BlockSim, from **Start** select **Programs**, **ReliaSoft Office**, **BlockSim** and then **BlockSim**. The figures used in this manual, as well as the commands required, are all from Windows 98. However, regardless of which operating system you are using, the BlockSim internal screens and commands are identical in all systems and this manual is equally applicable.

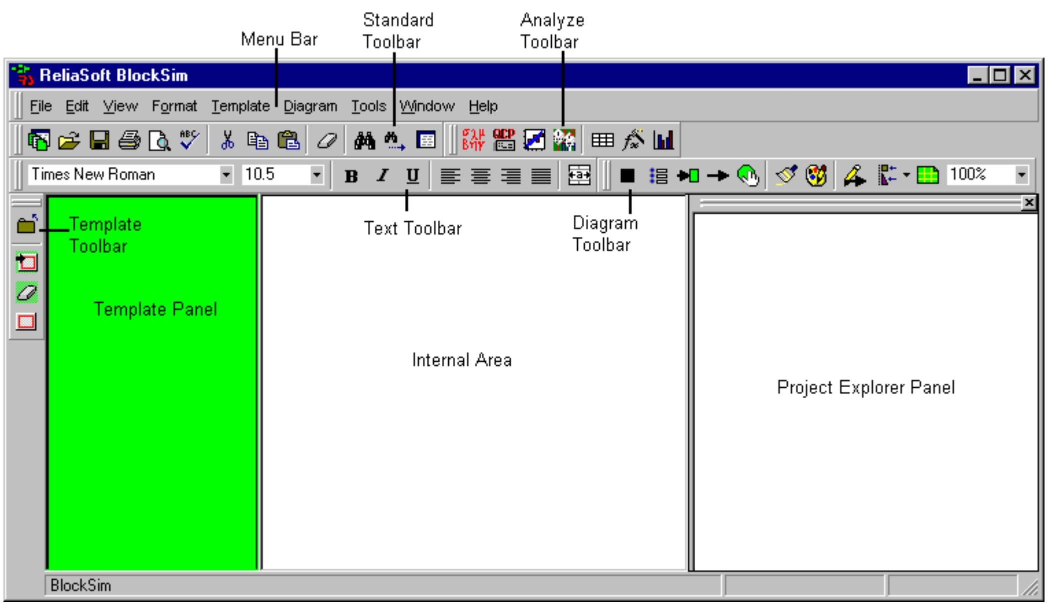


3.2 Multiple Document Interface

The Multiple Document Interface (MDI) is the main window and "manager" for BlockSim. The MDI serves as the container for all the windows you will use in BlockSim.

The menu and toolbar options available within BlockSim's MDI will vary depending on the windows that are currently open. In addition, BlockSim's flexible MDI allows the user to configure the work space to meet individual needs by hiding or moving the menu bar, toolbars, Project Explorer and Template Panel.

The next figure displays the MDI and its components so that you can familiarize yourself with the options available within the MDI. Your screen may look slightly different than the one shown next, depending on the windows and tools currently open and on the configuration settings that you have established.



3.3 Getting Help in the BlockSim Environment

ReliaSoft's BlockSim includes complete on-line help documentation. This help can be obtained at any time by pressing **F1** or by selecting **Contents** from the **Help** menu.

3.4 BlockSim: A Familiarization

3.4.1 A Quick Overview Example

This section presents you with a very simple example and guides you through the solution. A simple system consists of three resistors configured reliability-wise in series. The failure characteristics of each component are presented in the table shown next. Create a reliability block diagram (RBD) to represent the system, plot the Reliability vs. Time of the system and calculate the reliability of the system at 50 days of operation.

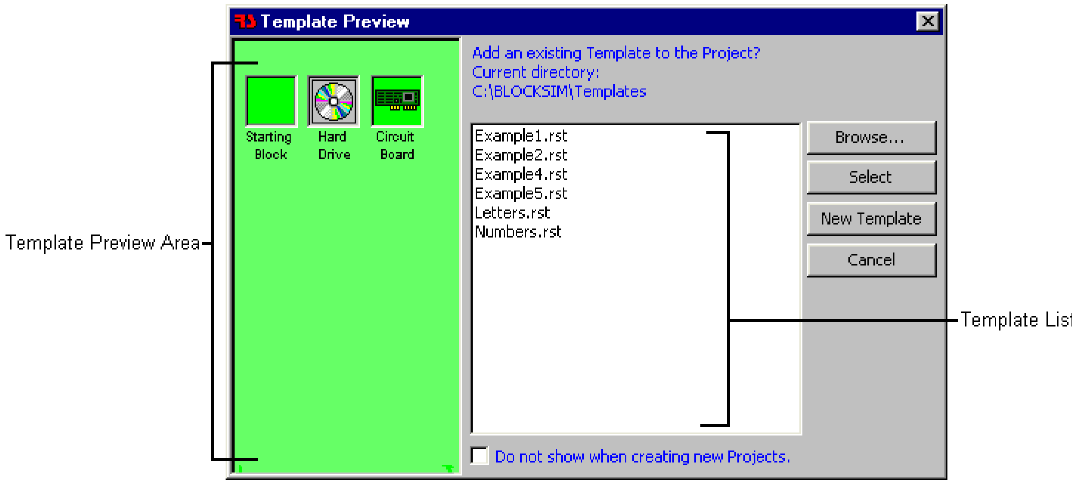
Component	Failure Distribution	Parameters
Resistor 1	Exponential	Mean Time = 1000 Gamma = 0
Resistor 2	Exponential	Mean Time = 500 Gamma = 0
Resistor 3	Exponential	Mean Time = 333.33 Gamma = 0

3.4.2 Create a New BlockSim Project

- The first step is to create a new project by clicking the **New Project** icon,

  or by selecting **New Project** from the **File** menu.

- The Template Preview window will be displayed to allow you to select an existing template or create a new template in the new project.

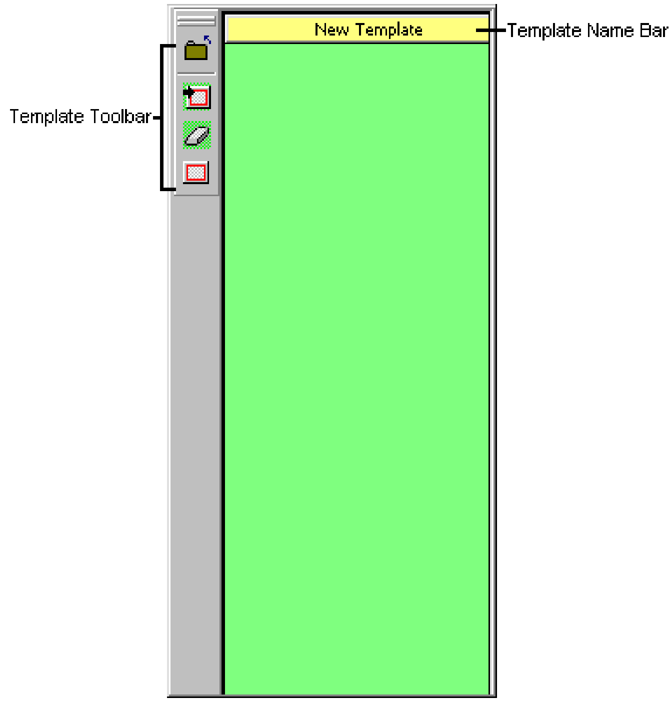


The Template Preview window allows you to preview and select from the existing BlockSim templates in the current directory. BlockSim's templates contain sets of re-usable pre-defined blocks, template blocks, which you can drag into the diagram sheets to create reliability block diagrams (RBDs). Select a template name from the template list to display the blocks the template contains in the preview area on the left. Click **Select** or double-click the template name to close the Template Preview window and open the selected template in the project. Click **Browse** to open a Browse For Folder window, which allows you to locate other previously saved templates in other directories. Click **New Template** to close the Template Preview window and create a new template in the project.

- For this example, you will create a new template within the project. Click the **New Template** button in the Template Preview window to open a new template in the project. [1]
- After you click **New Template**, you will be prompted to enter a name for the new template. Click **OK** to accept the default name. When you are prompted to enter a name for the new diagram sheet, which will also be created in the new project, click **OK** to accept the default name.

1. If the **Do not show when creating new Projects** option is selected, the Template Preview window will not be displayed when a new project is created. This selection can be reset on the Other page of the User Setup.

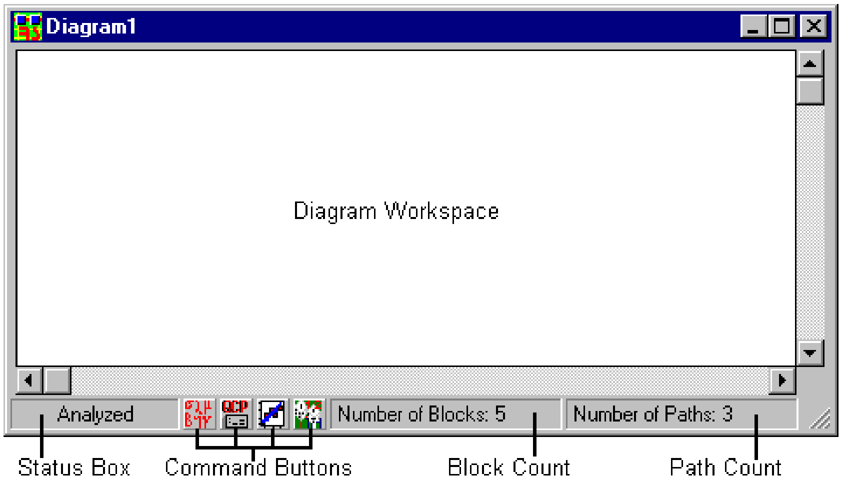
- The Template Panel, located on the left side of the MDI, will appear once you create a new template.[2] Notice that the Template Name Bar located at the top of the Template Panel displays the name of the new template, New Template, and that the Template Name Bar is yellow to indicate that the template is currently active.



> Multiple templates can be open at the same time within BlockSim. For each open template, a Template Name Bar will be displayed in the Template Panel. When you click a Template Name Bar, the template becomes active, the Template Name Bar becomes yellow and the blocks associated with the template are displayed in the Template Panel.

2. The Template Panel will only appear if **Show Template Panel** is selected from the **Template** menu.

- A new diagram sheet will also appear in the MDI, as shown next.



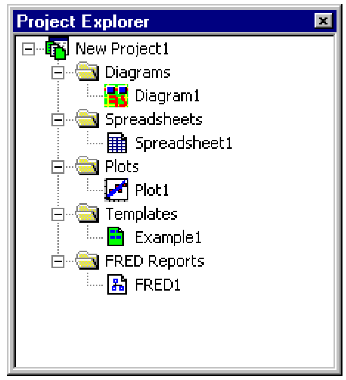
> The diagram sheet is the work space in which you will create simple or complex RBDs. You can configure blocks and relationship lines in the diagram workspace. At the bottom of the diagram sheet, the Status Box displays the analysis status (EDIT or Analyzed) of the diagram, the Command Buttons allow you to initiate analyses based on the diagram. Block Count displays the number of blocks in the diagram workspace and Path Count displays the number of paths that have been defined in the diagram sheet.

The Project Explorer will also appear in the MDI. The Project Explorer allows you to manage the files included in a single BlockSim project. From within the Project Explorer, you can add, import, export, rename and delete files within the current project.

The appearance of the Project Explorer will vary depending on whether **Dock Project Explorer** is selected from either the **Project Explorer** shortcut menu or from the **View** menu.[3] If **Dock Project Explorer** is selected, the Project Explorer will be displayed as a fixed panel on the right side of the MDI. If **Dock**

3. Right-click inside the Project Explorer to display a shortcut menu with the commands that pertain to BlockSim projects.

Project Explorer is not selected, the Project Explorer will be displayed as a window like the one shown next.

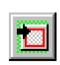


To perform your system analyses with BlockSim, you will create diagrams, spreadsheets, plots, templates and FRED reports. BlockSim allows you to store and organize the diagrams, spreadsheets, plots, templates and FRED reports related to a particular project together in a single file, a BlockSim project file (*.rsw).

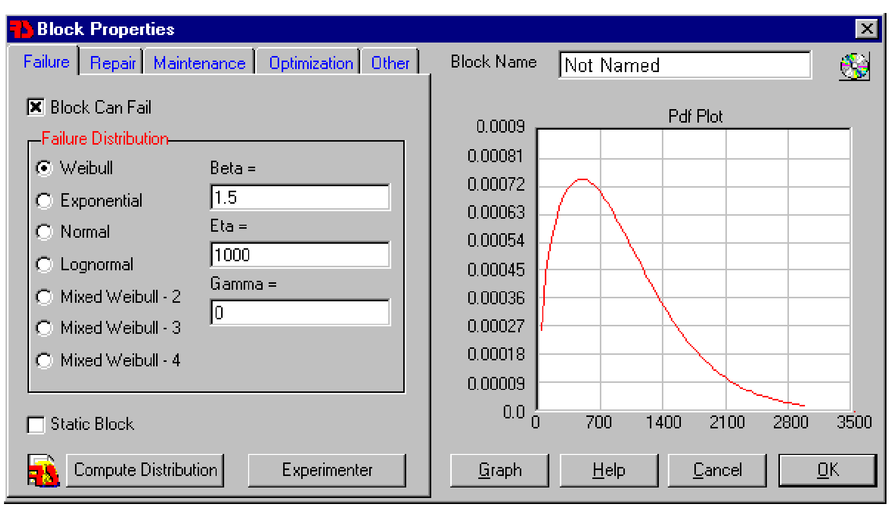
3.4.3 Creating a Template Block

The next step is to create a new template block that will be used as the pattern for the Resistor blocks you will use in your RBD. BlockSim blocks, defined with the reliability characteristics of system components, are the building blocks you will use to create your diagrams.

- To add a block to the active template, select **Add New Block** from the **Template** menu or click the **Add New Block** icon in the Template toolbar.

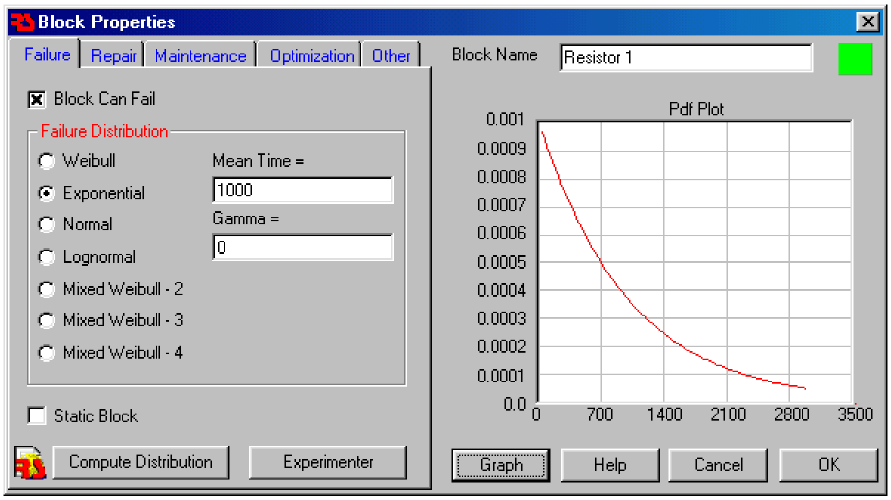


The Block Properties window will appear, as shown next, which allows you to define the new block with the life characteristics of the component.



- On the Failure page of the Block Properties window, you will define the block to represent the failure characteristics of the Resistor 1 component. Type **Resistor 1** in the Block Name input box. Verify that the **Block Can Fail** option is selected (*i.e.* the checkbox is checked).[4] Verify that the **Static Block** option at the bottom of the window is not selected. [5]

- Select **Exponential** under **Failure Distribution** and notice that the parameter input boxes to the right change to represent the parameter requirements of the selected distribution. Type **1000** for the value of Mean Time and **0** for the value of Gamma.[6] Click **Graph** to update the *pdf* plot in the graphics screen to the right. The *pdf* plot will now represent the current Failure page selections.
- The Block Properties window will look like the one shown next.



- Click **OK** to close the Block Properties window and create a new block in the active template.

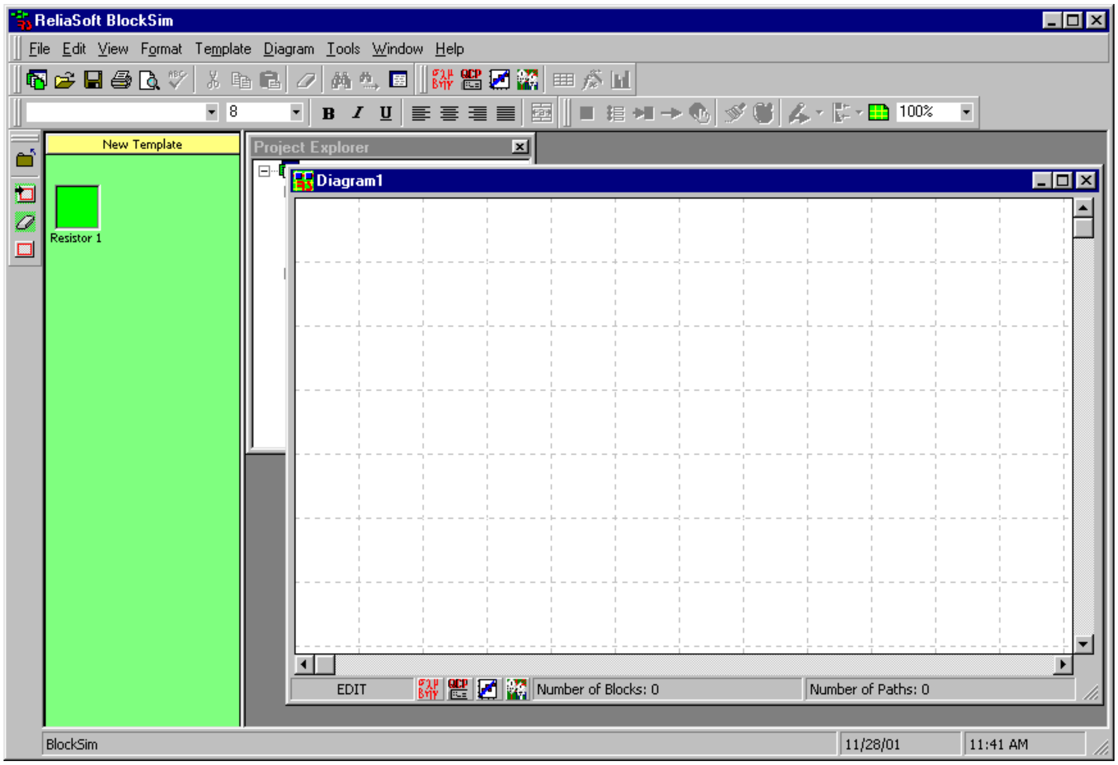
---

4. The **Block Can Fail** option is selected to indicate that the component can fail. If the **Block Can Fail** option is not selected, the reliability of the block at all times is considered to be 1 or 100% and the other options on the Failure page will be unavailable.

5. The **Static Block** option is not selected to indicate that a time-dependent failure distribution will be defined for the component. If the **Static Block** option is selected, an input box will appear in which you can type the reliability of the component at a fixed point in time and the other options on the Failure page will be unavailable.

6. By default in BlockSim, the Exponential parameter is defined as mean time. Although the mean time definition is appropriate for this example, you can also define the Exponential parameter as Lambda from the Calculations page of the User Setup.

- The Template Panel now holds a new block, as shown next.



- Repeat these steps to create two more template blocks to represent the Resistor 2 and Resistor 3 components. On the Failure page of the Block Properties window for the Resistor 2 block, make the following selections:

  Block Name: Resistor 2

  Block Can Fail: Selected

  Failure Distribution: Exponential

  Mean Time: 500

  Gamma: 0

  Static Block: Not Selected

- On the Failure page of the Block Properties window for the Resistor 3 block, make the following selections:

  Block Name: Resistor 3

  Block Can Fail: Selected

  Failure Distribution: Exponential

  Mean Time: 333.33

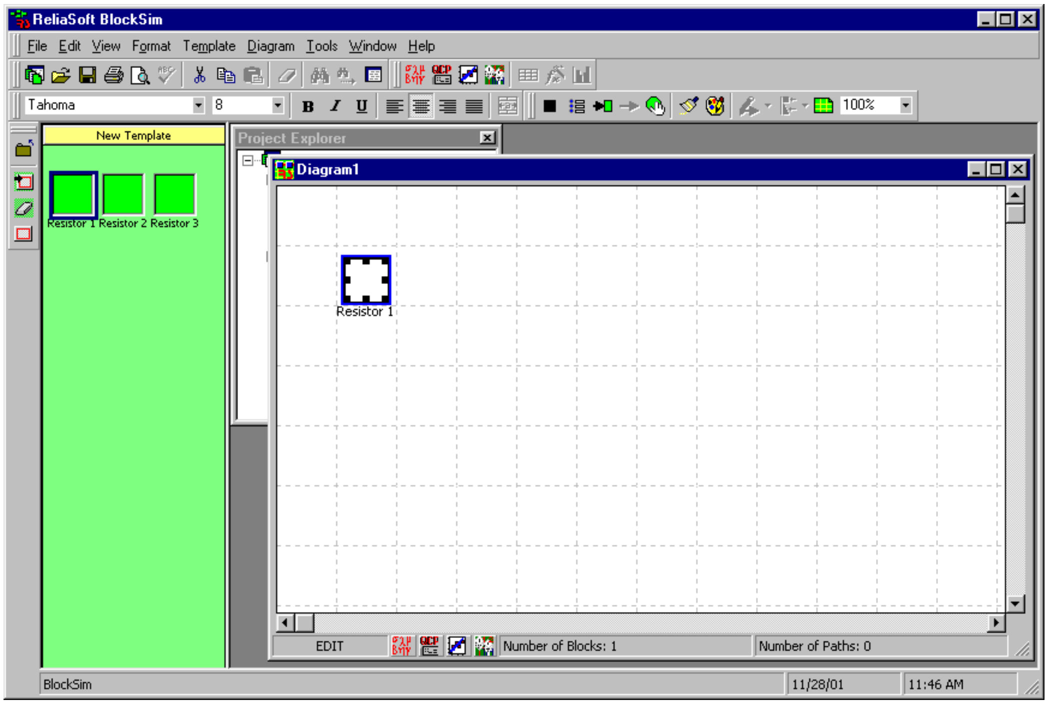
  Gamma: 0

  Static Block: Not Selected

3.4.4 Build a Simple Diagram

Now you are ready to build a simple reliability block diagram (RBD) by placing the template blocks you have created into the diagram sheet. You will do this by dragging the blocks from the Template Panel into the diagram sheet.

- Drag the Resistor 1 block into the diagram sheet. To do this, click the block in the Template Panel to select it, hold down the left mouse button, drag the cursor into the desired position on the diagram sheet and release the mouse button. Your screen will look like the figure shown next.



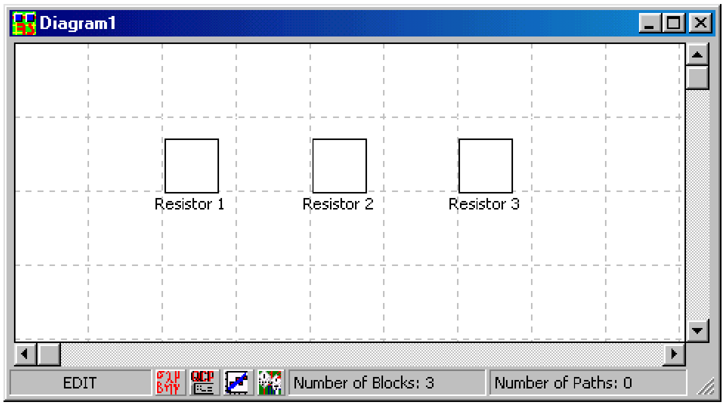
> Notice that a copy of the block is placed in the diagram sheet and the template block remains in the Template Panel. Template blocks are like re-usable patterns that you can use to save time and effort. When you drag a template block into a diagram sheet, a separate (independent) block is created in the diagram sheet that you can modify to meet the needs of the particular diagram.

- Next, drag the Resistor 2 and Resistor 3 blocks into the diagram sheet.

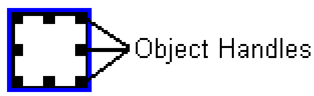
3.4.5 Arrange and Connect the Blocks

You are now ready to arrange and connect the blocks in the diagram sheet to create a reliability block diagram (RBD) that will represent the reliability-wise configuration of the system.

- Place the blocks in a horizontal row with Resistor 1 on the left, Resistor 2 in the middle and Resistor 3 on the right. Drag the blocks as before by clicking the block to select it, holding down the left mouse button, moving the cursor into the desired position and releasing the mouse button. Your diagram sheet will look like the next figure.

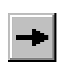


- Now you are ready to connect the blocks to represent the relationships between components of the system. Select the Resistor 1 component by clicking once on the block. When a block is selected, a blue outline will appear around the block and object handles will appear at each corner and on all four sides of the block, as shown next.



When you move the cursor over the object handles in the selected block, a circular target symbol appears at the tip of the arrow. This target symbol is the anchor for the relationship lines you will draw between blocks.

- Move the mouse over the object handles on the Resistor 1 block. When a target symbol appears, hold down the left mouse button and drag a line from the Resistor 1 block to the Resistor 2 block with which it will be connected. When the target symbol is located above the second object, release the mouse button. A relationship line will now connect the two blocks.
- You can also use the Join Blocks tool to connect blocks in the diagram sheet. Connect the Resistor 2 block with the Resistor 3 block by selecting **Join Blocks** from the **Diagram** menu or by clicking the **Join Blocks** icon.

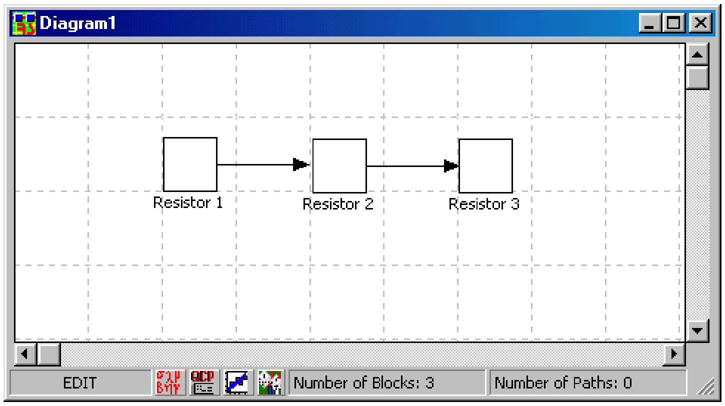


The cursor will change to display a target symbol at the tip of the arrow. Click the source block (Resistor 2), hold down the left mouse button and drag a line to the destination block (Resistor 3). When the target symbol is located above the second object, release the mouse button. The blocks will be connected with a relationship line. Note that when using the Join Blocks tool to create relationship lines, you must right-click the diagram sheet to stop adding relationships and return to BlockSim's normal mode.[7]

---

7. If you do not right-click the diagram sheet to return the cursor to its normal mode, you will not be able to perform other activities in BlockSim. If you are experiencing difficulties with the program, make sure that the cursor is in its normal mode. A dialogue balloon reminder appears in the upper right of the MDI when the Join Blocks tool is activated.

- Your diagram will now look like the next figure.[8]

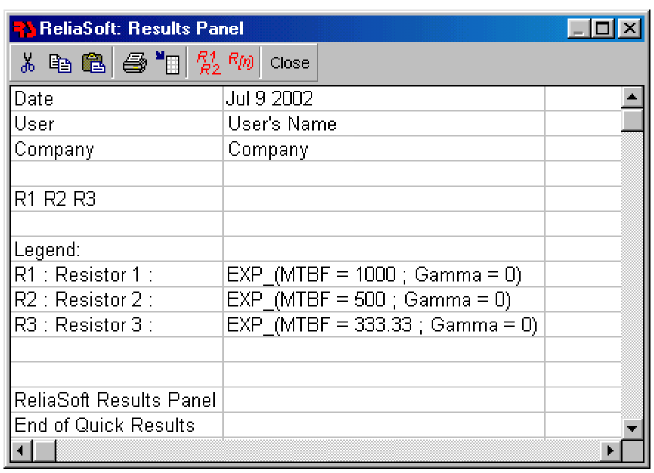


3.4.6 Analyze the Diagram

Now that you have defined the reliability characteristics of each component block and arranged and connected the blocks to represent the system, you are ready to analyze the diagram.

- Select **Analyze** from the **Tools** menu or click the **Analyze** icon.

- ReliaSoft's Results Panel will appear to display the results of the analysis, as shown next.[9]



- When you analyze a diagram, BlockSim analyzes the relationships of the components in the system and presents the reliability-wise configuration mathematically in ReliaSoft's Results Panel. Click **Close** to close the Result Panel and return to the diagram sheet.[10]

---

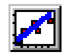
8. Notice that the connecting line arrows point from the source blocks to the destination blocks to represent the flow of the system. The specification of source and destination blocks is relevant to BlockSim's analysis of the system configuration.

9. Note that the first time you analyze a diagram in BlockSim, you will be prompted to indicate whether you would like to display the Results Panel each time a diagram sheet is analyzed. You can reset this preference on the Other page of the User Setup by clicking **Reset Settings**.

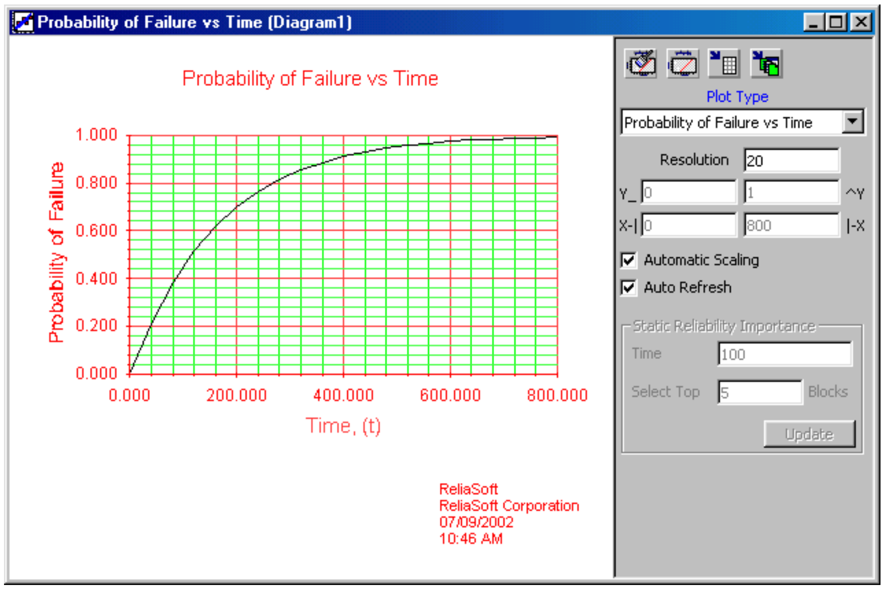
10. At this time, you may have noticed that the status in the Status Box in the bottom left corner of the diagram sheet has changed from EDIT to Analyzed to indicate that system relationships have been analyzed.

3.4.7 Plot System Reliability

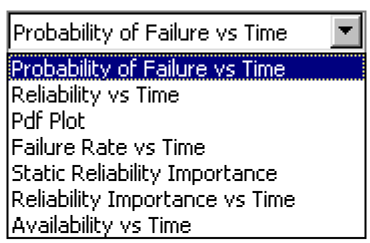
- Now you can generate plots based on the reliability characteristics of the entire system. Select **Plot** from the **Tools** menu or click the **Plot** icon.



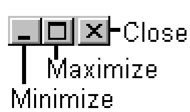
- The plot sheet will appear, displaying the Probability of Failure vs. Time plot, as shown next.[11]



Additional plots are also available in BlockSim's plot sheet, including Reliability vs. Time, *pdf*, Failure Rate vs. Time, Static Reliability Importance, Reliability Importance vs. Time and Availability vs. Time. Select a plot type from the Plot Type drop-down menu, as shown next.

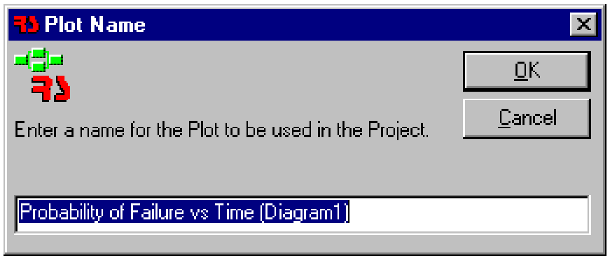


- Now close the plot by clicking the **Close** button in the top right corner of the plot sheet.

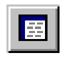


[11] If you have previously opened a plot sheet in BlockSim, the plot type of the last plot that was created will appear. If a plot other than the Probability of Failure vs. Time plot appears, select **Probability of Failure vs. Time** from the Plot Type drop-down menu.

- When you are asked if you want to insert the plot into the project, click **Yes**. A Plot Name window will appear, as shown next. Type a plot name and click **OK** or click **OK** to accept the default name.



- Click the **Project Explorer** icon to place the focus on the Project Explorer.



You can see that a plot file has been added to the project in the Plots directory of the Project Explorer. Now return the focus to the diagram sheet, Diagram 1, by double-clicking its name in the Project Explorer.

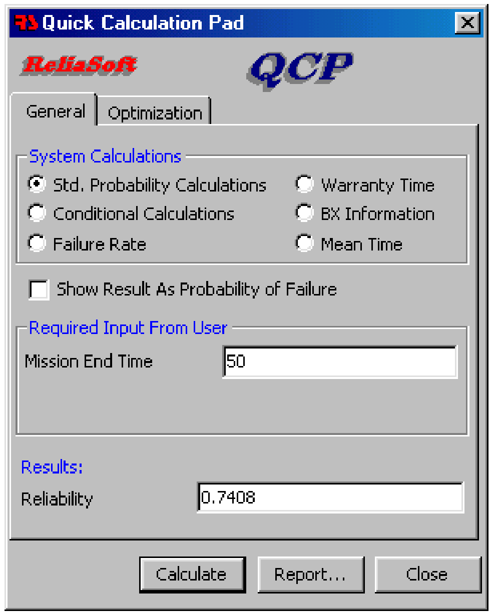
3.4.8 Calculate System Reliability

In addition to generating system reliability plots, BlockSim is also capable of calculating standard system reliability metrics based on the exact system reliability function.

- To calculate the reliability of the system at a specified time, select **Quick Calculation Pad** from the **Tools** menu or click the **QCP** icon.

The Quick Calculation Pad (QCP) will appear. Standard reliability calculations can be obtained using the first page of the QCP, the General page.

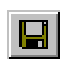
- To determine the reliability of the system at 50 days, select **Std. Probability Calculations** under System Calculations. Under Required Input from User, enter a Mission End Time of **50**. Finally, click **Calculate** and the results of the calculation will appear under Results, as shown next.



- You can see that the reliability of the system at 50 days is 0.7408 or about 74.08%. Click **Close** to close the Quick Calculation Pad and return to the diagram sheet.

3.4.9 Save and Close the Project

Now save the project as **1stStep.rsw**. To do this, select **Save Project** from the **File** menu or click the **Save Project** icon.



In the Save Project As window, enter **1stStep** as the filename and click **Save**. If you are working with an evaluation copy of BlockSim, you will not be able to save the project. In this case, leave the project open and proceed with the rest of the examples in the training guide.

After saving the file, close the project by selecting **Close Project** from the **File** menu. You will now be looking at the MDI without any projects open.

4 Step-by-Step Examples

4.1 Detailed Examples

4.1.1 Example 1

A computer consists of two Hard Drives and a Circuit Board. The two Hard Drives operate reliability-wise in parallel within the system. The reliability and optimization characteristics of each component are presented in the table shown next.

Component	Failure Distribution	Parameters	Max Achievable Reliability	Feasibility of Increasing Reliability
Hard Drive 1	Weibull	Beta = 2.5 Eta = 3000 days Gamma = 0	.999	Moderate
Hard Drive 2	Exponential	Mean Time = 10000 Gamma = 0	.999	Easy
Circuit Board	Weibull	Beta = 1.5 Eta = 5000 days Gamma = 0	.999	Hard

Do the following:

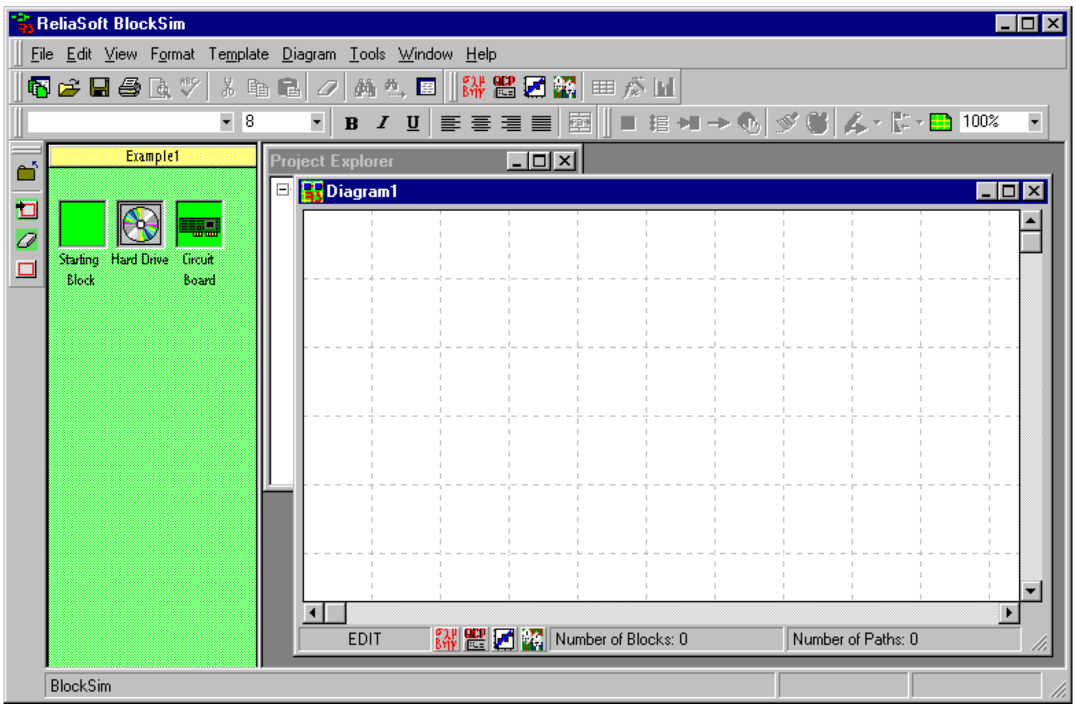
- Create a reliability block diagram (RBD) of the system.
- Calculate the reliability of the system at 730 days (2 years) of operation.
- Calculate the reliability of the system at 730 days if the Hard Drive 1 component is removed from the system.

- Determine the optimum scenario for increasing the reliability of each component in order to achieve a system reliability of 0.98 (or 98%) at 730 days of operation.

Solution

- Create a new project by selecting **New Project** from the **File** menu or by clicking the **New Project** icon.

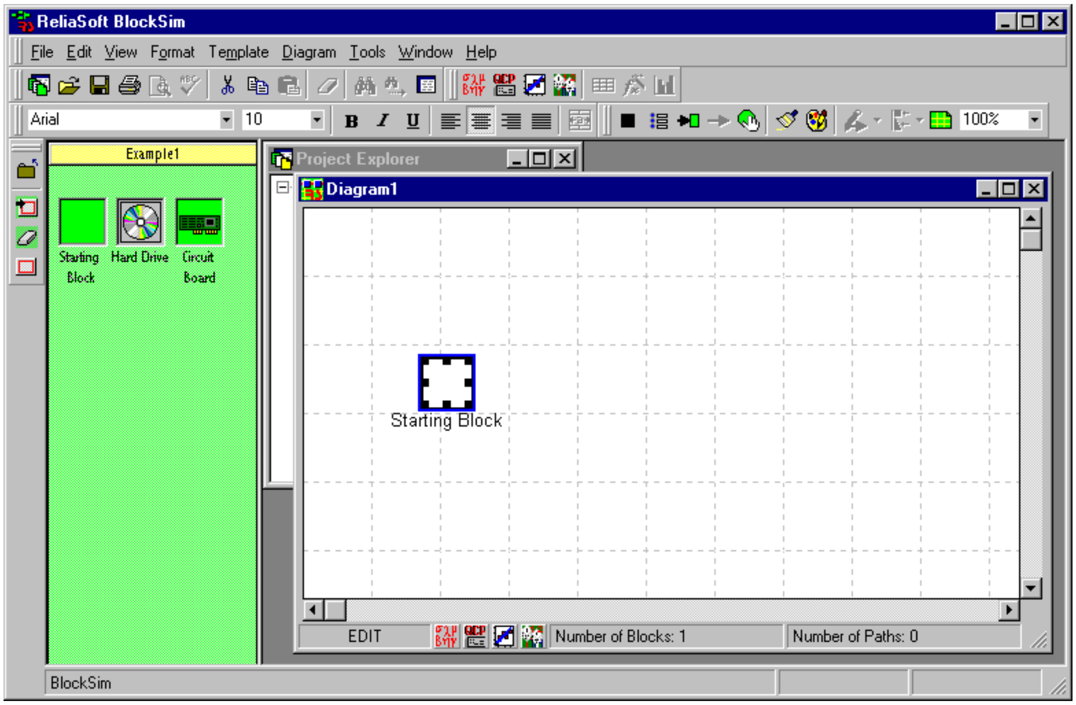
Select the **Example1.rst** template from the Template Preview window and click **Select**. The selected template will open in the new project. You will be prompted to enter names for the new diagram sheet. Accept the default name. The Project Explorer and a blank diagram sheet will appear. Your screen will look like the picture shown next.



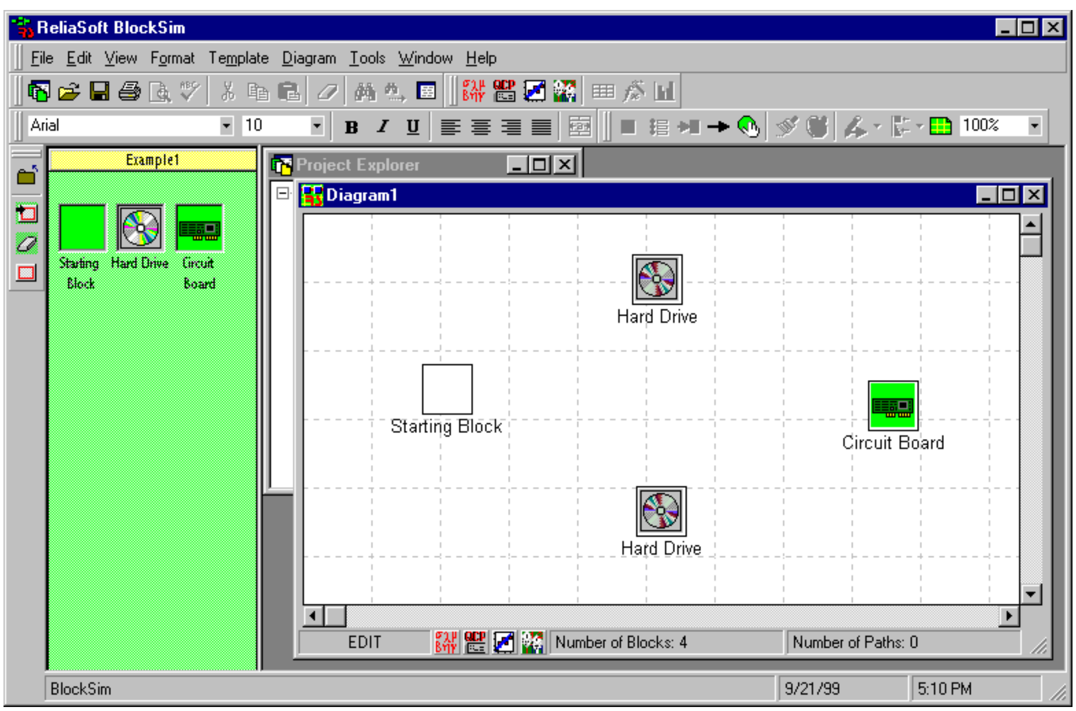
- The diagram sheet is the workspace in which you will create simple or complex diagrams that represent the reliability characteristics of systems or processes. The Project Explorer appears behind the diagram sheet. View the Project Explorer by clicking on it behind Diagram 1, by selecting **View Project Explorer** from the **View** menu or by clicking its icon.

- The template, Example1, appears in the Template Panel on the left side of the MDI. You are now ready to build a simple reliability block diagram (RBD) by dragging blocks from the Example1.rst template into the diagram sheet.
- Place the focus on Diagram 1 again by double-clicking its name in the Project Explorer or by clicking the diagram itself located behind the Project Explorer.
- Drag the Starting block into the diagram sheet. To do this, click the block in the Template Panel to select it, hold down the left mouse button, drag the cursor into the desired position on the diagram sheet and

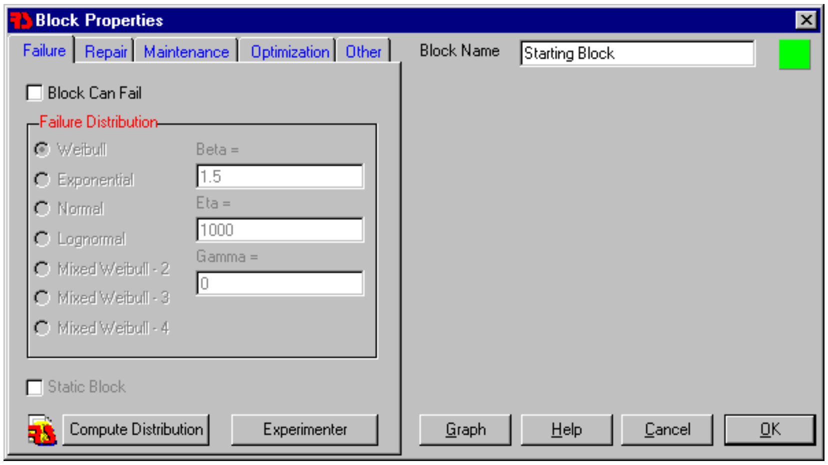
release the mouse button. The Starting block will represent the starting point of the computer system in this example. Your screen will look like the figure shown next.



- Now drag the Hard Drive and Circuit Board blocks from the Template Panel into the diagram sheet. Drag a second Hard Drive block into the diagram to represent the second Hard Drive component in the system. The diagram sheet will now contain four blocks and the Example1.rst template will be unchanged, as shown next.

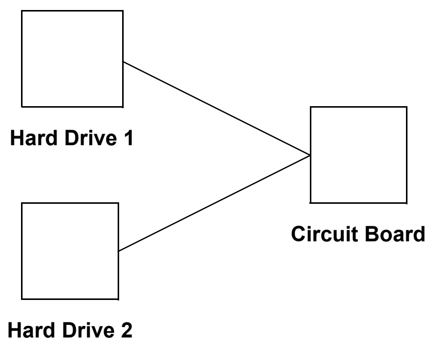


- Double-click the Starting block in the diagram sheet to open the Block Properties window, shown next.



In this window, you can define the reliability characteristics of the component. Because this block does not represent a component of the system with failure characteristics to be taken into account, de-select the **Block Can Fail** option to indicate that the component cannot fail. Because the component cannot fail, the other options on the Failure page are unavailable. Click **OK** to close the Block Properties window.

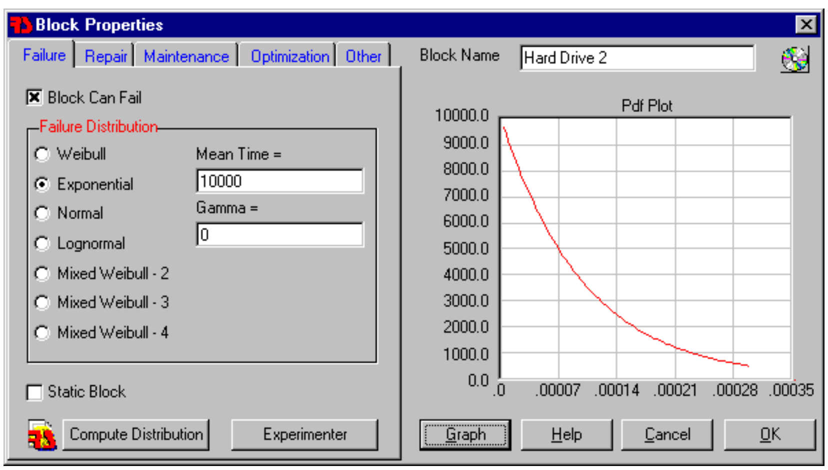
- The Starting block is defined as a block that cannot fail. The system in this example contains only three components: two Hard Drives and a Circuit Board. The Hard Drives are connected in parallel. Therefore, the original system would look like the figure shown next.



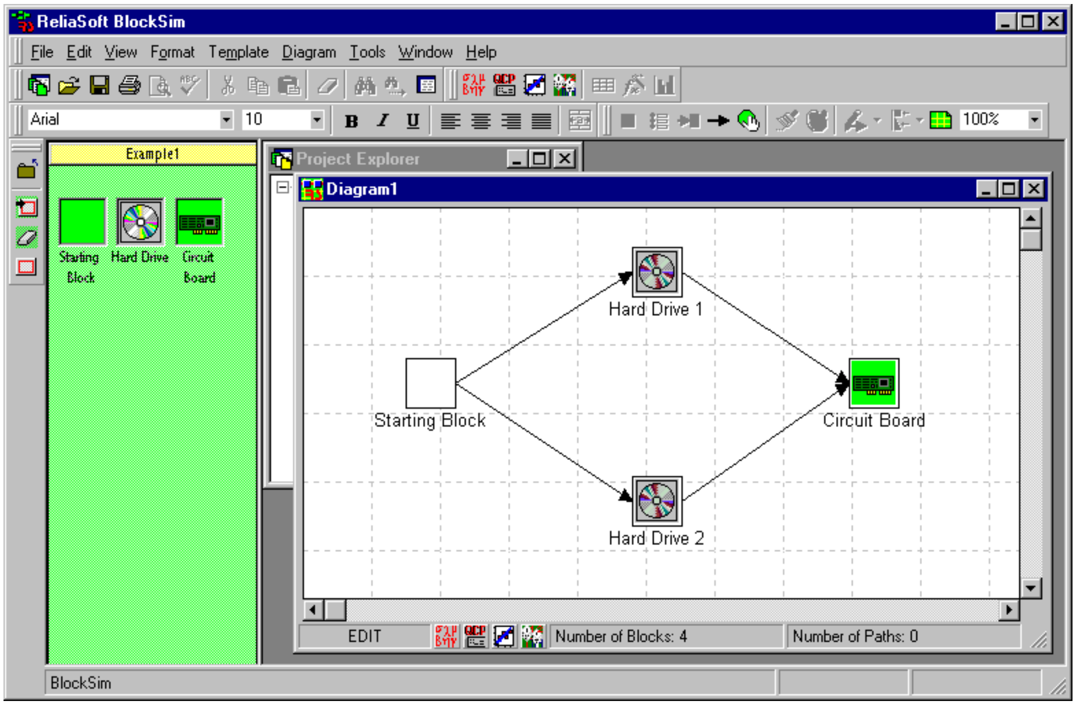
However, this original system contains two starting points (Hard Drive 1 and Hard Drive 2). A BlockSim diagram must have exactly one starting point and one ending point. Therefore, a single starting point (represented by the Starting block) that does not possess failure characteristics was introduced to close the system without impacting reliability calculations.

- The Circuit Board block has also already been defined with the failure characteristics of that component. The failure distribution properties have already been set in the template block. Move the mouse over each block within the template to view the pop-up tool tip text. The tool tip text displays the failure distribution properties of the block over which the cursor is positioned. You can change the properties of the block within the diagram sheet or within the template. If you change the properties of a block within the template, then each time the block is dragged into the diagram sheet, the block's properties will reflect the values specified in the template.

- Now, double-click the Hard Drive block at the top of the diagram sheet to define the characteristics of the Hard Drive 1 block. Be sure that the following options and properties have been defined:
    - **Block Name:** Hard Drive 1
    - **Block Can Fail:** Selected
    - **Failure Distribution:** Weibull
    - **Beta:** 2.5
    - **Eta:** 3000 days
    - **Gamma:** 0
    - **Static Block:** Not Selected
- Click **OK** to close the Block Properties window.
- Double-click the other Hard Drive block to define the Hard Drive 2 block. Be sure that the following options and properties have been defined:
    - **Block Name:** Hard Drive 2
    - **Block Can Fail:** Selected
    - **Failure Distribution:** Exponential
    - **Mean Time:** 10000
    - **Gamma:** 0
    - **Static Block:** Not Selected
- Click **Graph** to update the *pdf* plot to graphically represent the current failure distribution. The window will look like the next figure.



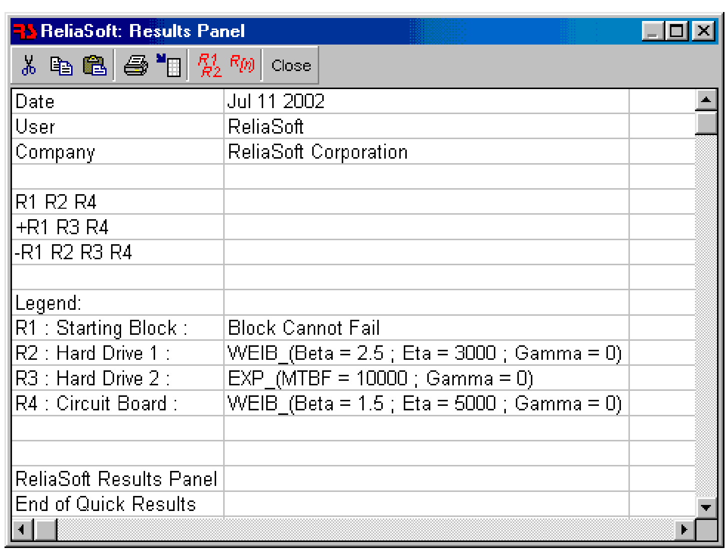
- Now you are ready to connect the blocks to represent the relationships between the components of the system. Use either connection method to connect the Starting Block to the Hard Drive 1 block, the Starting Block to the Hard Drive 2 block, the Hard Drive 1 block to the Circuit Board block and the Hard Drive 2 block to the Circuit Board block. If you use the Join Blocks tool to add relationship lines, be sure to right-click the diagram once the relationships have been made in order to return to BlockSim's normal mode. Your screen will look like the next figure.



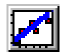
Notice that the Hard Drive blocks are diagrammed in parallel to show that if one Hard Drive component fails, the system will continue to operate with the other hard drive component. Now that you have defined the reliability characteristics of each component block and arranged and connected the blocks to represent the system, you are ready to analyze the system.

- To analyze the system, select **Analyze** from the **Tools** menu or click the **Analyze** icon.

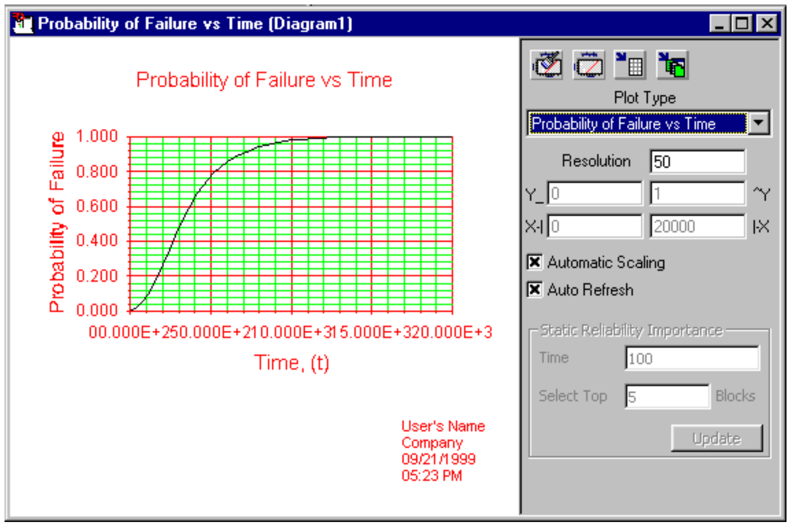
- ReliaSoft's Results Panel will appear, displaying the results of the analysis, as shown next. Click **Close** to close the Result Panel.



- Now you can generate plots based on the reliability characteristics of the entire system. Select **Plot** from the **Tools** menu or click the **Plot** icon.



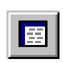
The plot sheet will appear, displaying the Probability of Failure vs. Time plot, as shown next.



- Click the **Add Plot to Project** icon to add the plot to the project.

The Plot Name window will appear, which allows you to name the plot. Click **OK** to accept the default name, Probability of Failure vs. Time (Diagram 1).

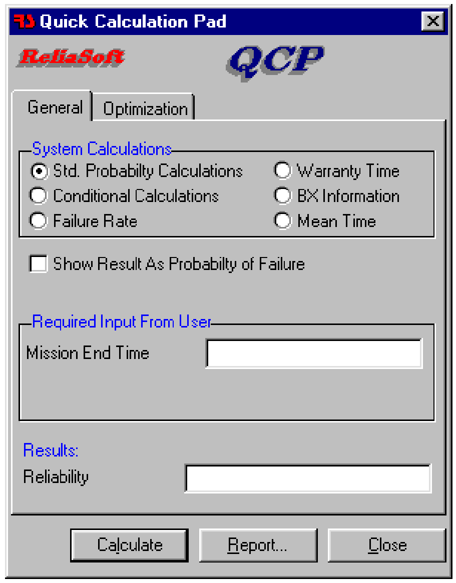
- Now view the Project Explorer by selecting **Project Explorer** from the **View** menu or by clicking the **View Project Explorer** icon.



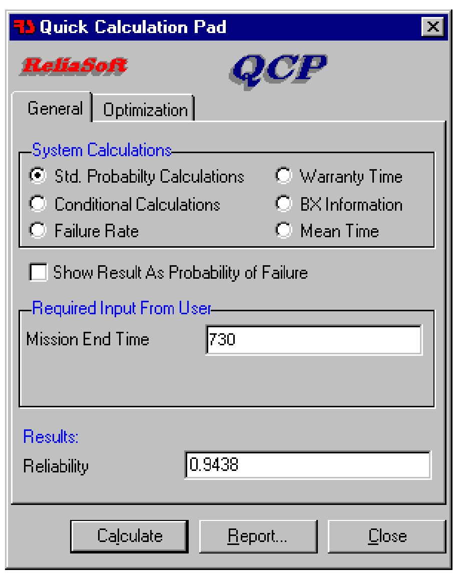
You will notice that Probability of Failure vs. Time (Diagram 1) has been added to the project under Plots in the Project Explorer. Now return the focus to the plot sheet. Close the plot by clicking the **Close** (**X**) button in the top right corner of the plot sheet. You will now be looking at the diagram sheet.

- BlockSim also allows you to obtain standard reliability results based on the exact system reliability function. To calculate the reliability of the system at 730 days, the Quick Calculation Pad (QCP) will be used. Select **Quick Calculation Pad** from the **Tools** menu or click the **QCP** icon.

The QCP will appear, as shown next.



- The QCP contains two pages, the General page and the Optimization page. On the General page, select **Std. Probability Calculations** under System Calculations to determine the reliability of the system. Under Required Input from User, type a Mission End Time of **730**. Finally, click **Calculate** and the results of the calculation will appear under Results, as shown next.



You can see that the reliability of the system at 730 days is 0.9438 or 94.38%. Click **Close** to close the Quick Calculation Pad and return to the diagram sheet.

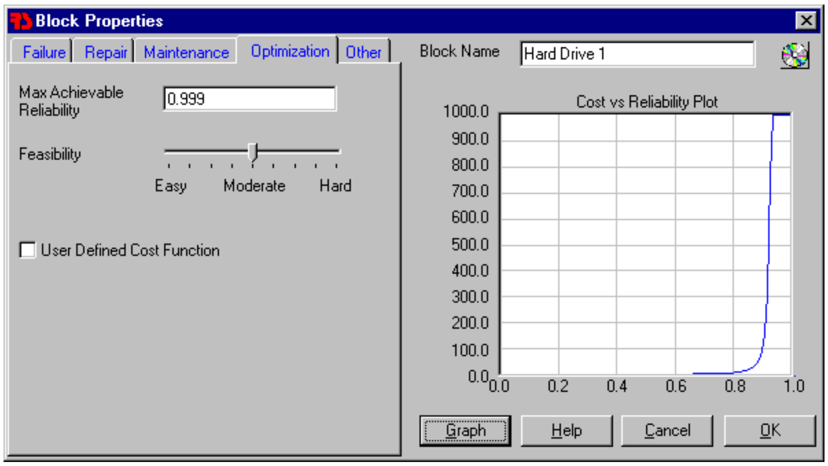
- Next, you will determine the reliability of the system if Hard Drive 1 is turned off or absent from the system. BlockSim allows you to perform “what-if” calculations based on the RBDs you create. You can toggle the status of individual blocks on or off to indicate whether the component is active or inactive and then obtain reliability results for the system under those hypothetical conditions.

- To toggle the status of Hard Drive 1 to "off," right-click the block and select **Toggle Block On/Off** from the shortcut menu that appears.[1] A red **X** will appear on the block to indicate that the component is inactive, as shown next.

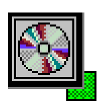
- Now re-open the QCP. Select the **Std. Probability Calculations** option and specify **730** as the Mission End Time. Click **Calculate** and the results will be displayed under Results. You can see that with Hard Drive 1 inactive, the reliability of the system at 730 days decreases from 0.9438 (94.38%) to 0.8792 (87.92%). Close the QCP.
- Now toggle the status of the Hard Drive 1 block back to "on" by de-selecting the **Toggle Block On/Off** option from the shortcut menu. The red **X** will disappear, indicating that the component is active.

[1] You can also click the block to select it and then select **Toggle Block On/Off** from the **Diagram** menu.

- BlockSim also provides the capability of performing optimization calculations to determine the best way to achieve a system reliability goal by improving the reliability of individual components. Double-click the Hard Drive 1 block to open the Block Properties window. Click the **Optimization** tab to display the Optimization page. On this page, you can define the optimization characteristics of the selected component. Enter **0.999** (default) into the Max Achievable Reliability input box to indicate the highest reliability value that can reasonably be achieved for the component. Drag the marker on the Feasibility scale to **Moderate** to indicate that it is moderately difficult (or costly) to increase the reliability of the component. Click **Graph** to update the Cost vs. Reliability plot in the graphics screen to the right. The window will look like the next figure.



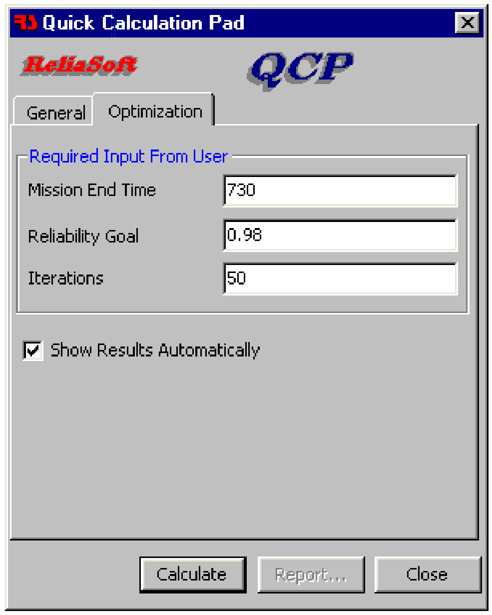
- Click **OK** to return to the diagram sheet. Now, right-click the Hard Drive 1 block and select **Toggle Optimize Status** from the **Diagram Block** shortcut menu.[2] A green box will appear at the bottom right corner of the block, as shown next, to indicate that the reliability of this component is to be considered in the optimization algorithm.



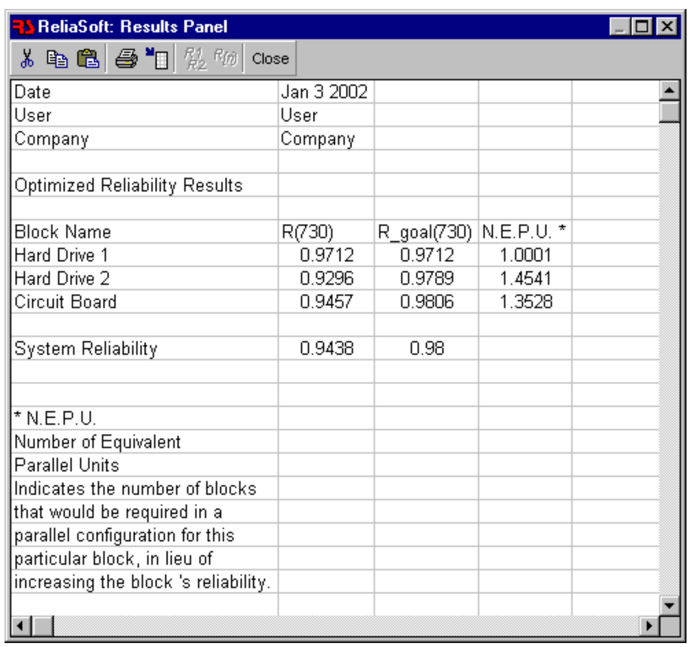
- Repeat these steps to define the optimization characteristics of the Hard Drive 2 and Circuit Board blocks. For the Hard Drive 2 block, the Max Achievable Reliability is 0.999 and the Feasibility is Easy. For the Circuit Board block, the Max Achievable Reliability is 0.999 and the Feasibility is Hard. Be sure to select the **Toggle Optimize Status** option for both blocks.
- Re-open the QCP and click the **Optimization** tab. The Optimization page allows you to set up and conduct the optimization algorithm for the system. For Mission End Time, type **730**; for Reliability

2. You can also select the block and then select **Toggle Optimize Status** from the **Diagram** menu.

Goal, type **0.98**; for Iterations, accept the default value of **50**.[3] Select the **Show Results Automatically** option, as shown next.



- Click **Calculate** to begin the optimization. Because the **Show Results Automatically** option is selected, when the optimization calculations are complete, the results will appear in ReliaSoft's Results Panel, as shown next.[4]



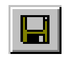
Date	Jan 3 2002		
User	User		
Company	Company		
Optimized Reliability Results			
Block Name	R(730)	R_goal(730)	N.E.P.U. *
Hard Drive 1	0.9712	0.9712	1.0001
Hard Drive 2	0.9296	0.9789	1.4541
Circuit Board	0.9457	0.9806	1.3528
System Reliability	0.9438	0.98	
* N.E.P.U.			
Number of Equivalent			
Parallel Units			
Indicates the number of blocks			
that would be required in a			
parallel configuration for this			
particular block, in lieu of			
increasing the block 's reliability.			

3. The Iterations input box allows you to enter the maximum number of iterations of the optimization algorithm to be calculated in order to obtain a solution. As the complexity and number of units in the system increases, a greater number of iterations may be required.

4. If the **Show Results Automatically** option is not selected, you can click the **Report** button to display the results in ReliaSoft's Results Panel.

The reliability goals for each optimized component, displayed in the R_goal(730) column, represent the optimum scenario for increasing component reliability in order to achieve the system reliability goal of 0.98 (or 98%) while minimizing the system cost. The number of equivalent units that would have to be placed in parallel to achieve this reliability is shown in the N.E.P.U. column, which stands for Number of Equivalent Parallel Units. Click **Close** to close the Result Panel and click **Close** to close the Quick Calculation Pad.

- At this time, save the project as **Example1.rsw**. To do this, click the **Save Project** icon or select **Save Project** from the **File** menu.



- In the Save Project As window, enter **Example1** as the filename and click **Save**. After saving the file, leave the project open, as it will be used in the next example.

4.1.2 Example 2

The Circuit Board from Example 1 was examined further to determine the major failure modes so that its reliability could be improved. It was found that most of the failures were due to the failure of the Processor and the Fan. The properties for the Processor and Fan are shown in the table below.

Component	Failure Distribution	Parameters	Max Achievable Reliability	Feasibility of Increasing Reliability
Processor	Weibull	Beta = 2.3 Eta = 7655.19 days Gamma = 0	.999	Moderate
Fan	Exponential	Mean Time = 14231.83 Gamma = 0	.999	Easy

The Processor and Fan are connected reliability-wise in series.

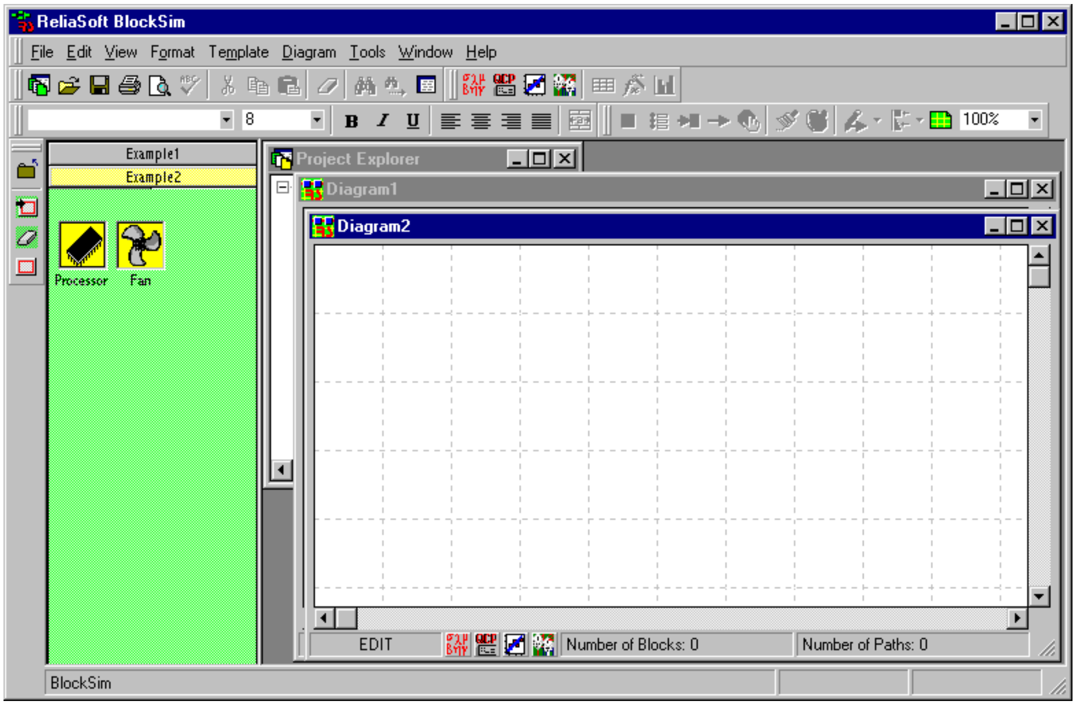
Do the following:

- Create an RBD for this subsystem.
- In the previous example, it was found that the reliability of the Circuit Board would be increased from 0.9457 to 0.9806 for the system to reach a reliability goal of 0.98. Find the optimized reliabilities for the Processor and Fan in order to achieve this goal.

Solution

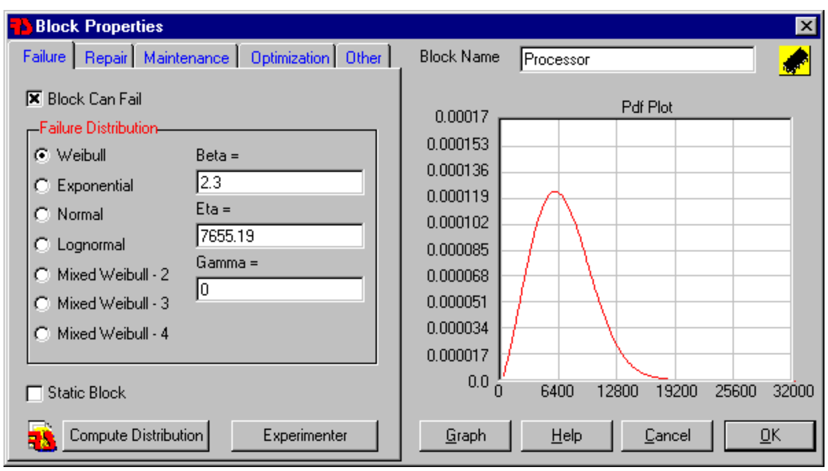
- First, insert another diagram into the project. To do this, select **Add New File** from the **File** menu and then **Add New Diagram** or right-click inside the Project Explorer and select **Add New File** then **Add New Diagram** from the shortcut menu. A new, blank diagram sheet will be placed into the project under Diagrams in the Project Explorer and it will also appear in the MDI.
- Next, open an existing template called Example2.rst. To do this, select **Import File** then **Template** from the **File** menu or right-click inside the Project Explorer and select **Import File** then **Template**. The

Template Preview window will open. Select the **Example2.rst** file from the list of files (in the BlockSim\Templates directory) and click **Select**. Your screen will look like the next figure.

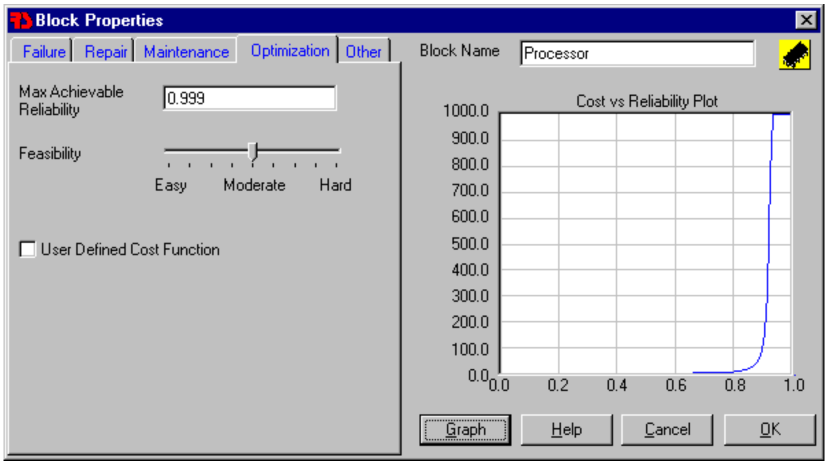


You can now see that two templates are open at the same time. The active template is indicated by a yellow bar in the Template Panel. You can switch between templates by clicking the bar with the template's name.

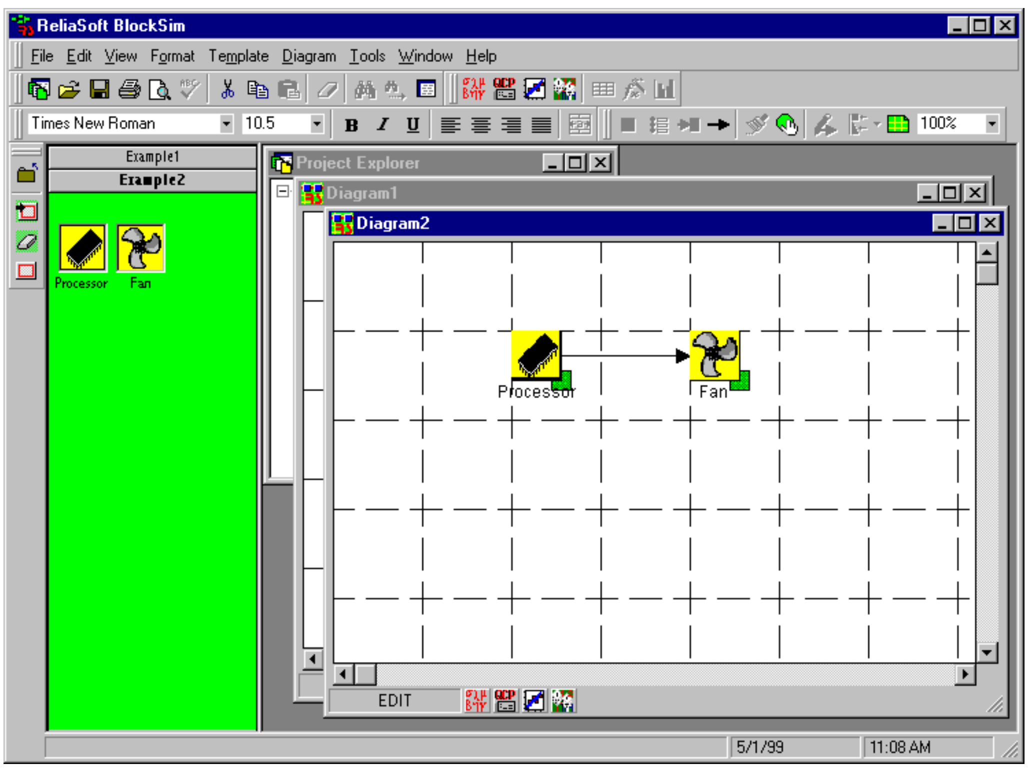
- Double-click the Processor block in the Example2 template to open the Block Properties window. Be sure that the **Block Can Fail** option is selected on the Failure page. Next, select **Weibull** as the failure distribution and enter the known parameter values (see table on page 32). Click **Graph** to view the *pdf* plot for the current parameter values based on the selected distribution. Your screen will look like the figure shown next.



- Now click the **Optimization** tab to display the Optimization page of the Block Properties window. Type the proper values for the Max Achievable Reliability and select the correct **Feasibility** option, as shown next. Be sure to click **Graph** so that the Cost vs. Reliability plot reflects the current settings.

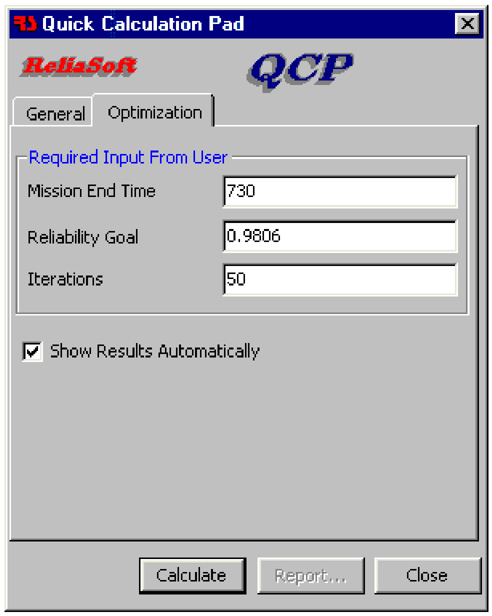


- Click **OK** to accept the current block properties and close the window.
- Double-click the Fan block in the template to open the Block Properties window and enter the appropriate block properties for the Fan using the same process described for the Processor. After you have entered all of the properties, click **OK**.
- Now drag one Processor block and one Fan block from the template into Diagram 2 and connect the blocks by dragging a relationship line from the Processor block to the Fan block.
- Right-click the Processor block and select **Toggle Optimize Status** from the shortcut menu. A green box will appear at the bottom right corner of the block to indicate that the reliability of this component is to be optimized. Do the same for the Fan block. Your screen will look like the figure shown next.

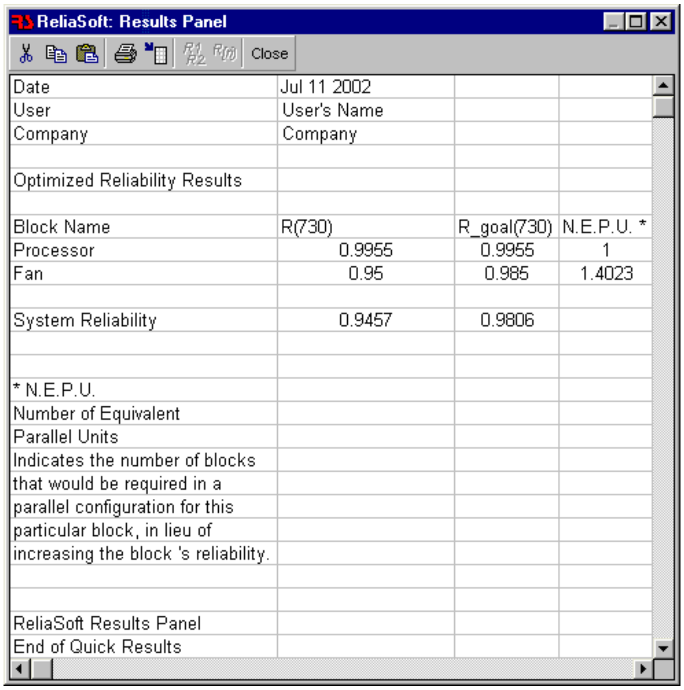


- Analyze the system by selecting **Analyze** from the **Tools** menu or by clicking the **Analyze** icon.

- ReliaSoft's Results Panel will appear, displaying the results of the analysis. Click **Close** to close the Results Panel.
- Next, optimize the reliabilities of the Processor and Fan so that the system reliability meets the reliability goal of 0.9806. Open the Quick Calculation Pad (QCP) and click the **Optimization** tab. Make sure that **730** is entered for the Mission End Time, the Reliability Goal is set at **0.9806** and the number of Iterations is **50** (default). In addition, **Show Results Automatically** will be selected. The QCP will look like the next figure.



- Click **Calculate** to conduct the optimization calculations. The results are shown next.



ReliaSoft: Results Panel

Date	Jul 11 2002		
User	User's Name		
Company	Company		
Optimized Reliability Results			
Block Name	R(730)	R_goal(730)	N.E.P.U. *
Processor	0.9955	0.9955	1
Fan	0.95	0.985	1.4023
System Reliability	0.9457	0.9806	
* N.E.P.U.			
Number of Equivalent			
Parallel Units			
Indicates the number of blocks			
that would be required in a			
parallel configuration for this			
particular block, in lieu of			
increasing the block 's reliability.			
ReliaSoft Results Panel			
End of Quick Results			

As the results indicate, to achieve a reliability goal of 0.9806, the reliability of the Processor must be at least 0.9955 and the reliability of the Fan must be at least 0.985.

- Click **Close** to close the Results Panel and click **Close** to close the QCP. Save the project as **Example2.rsw** and leave the project open, as it will be used in the next example.

4.1.3 Example 3

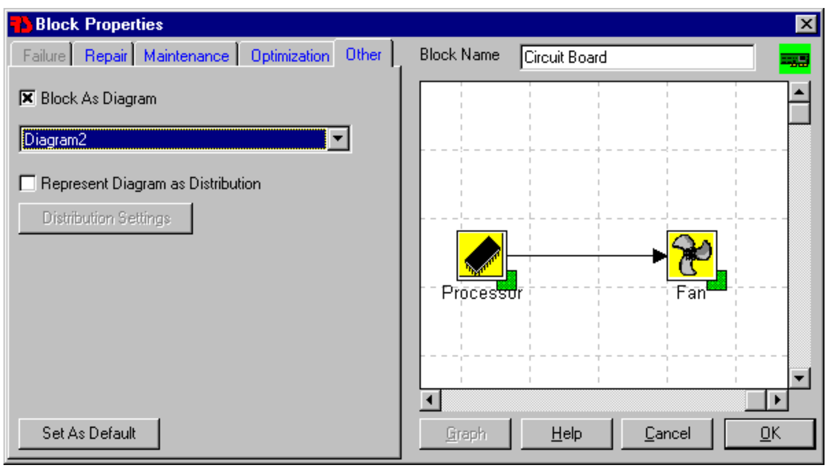
In BlockSim, you have the ability to include subsystems within selected blocks. This allows you to drill down or view the subsystems within a particular component. This example will demonstrate this aspect of BlockSim. At this point, you will still be working with the data and diagrams used in Examples 1 and 2.

Do the following:

- Include the Fan and Processor as a subsystem within the Circuit Board block.
- Calculate the reliability of the system at 730 days.

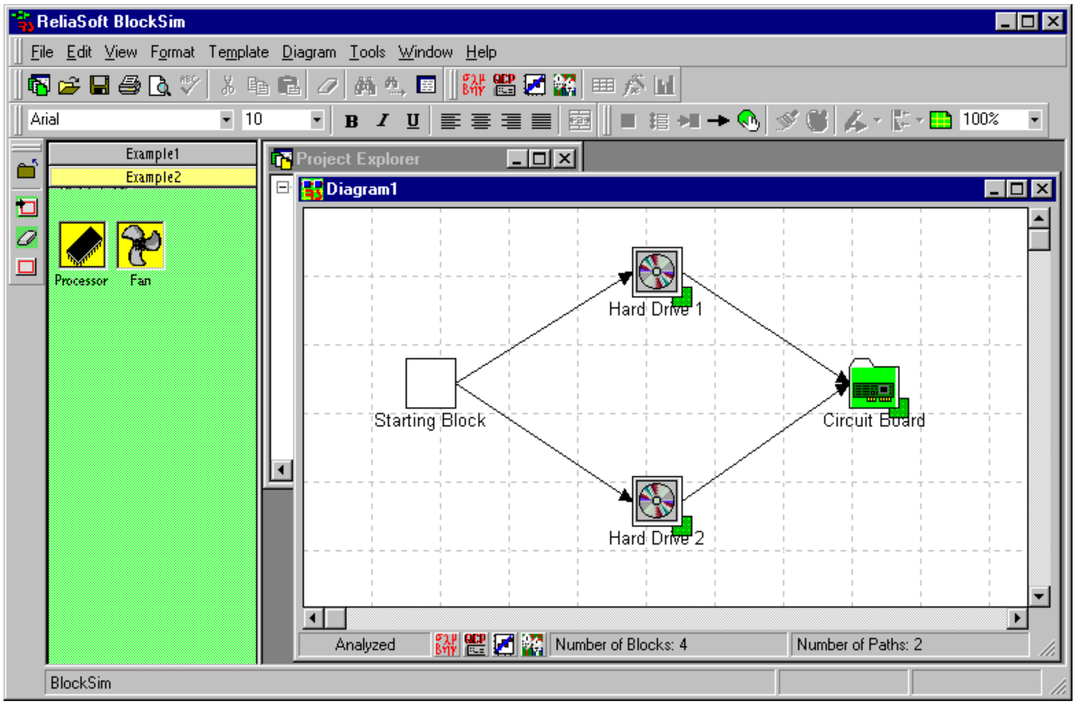
Solution

- To begin, return the focus to Diagram 1. This is the diagram with two Hard Drives and a Circuit Board. Double-click the Circuit Board block to open the Block Properties window.
- In the Block Properties window, click the **Other** tab. On the Other page, select the **Block As Diagram** option. Below the Block As Diagram option, a drop-down menu will appear. This menu contains a list of all available diagrams in the current project. Select **Diagram2** from this list. This is the file with the Processor and the Fan that you were working with in Example 2. The selected diagram will be displayed in the graphics screen on the right side of the Block Properties window. Your screen will look like the figure shown next.



You can zoom in on the diagram displayed in the graphics screen by left-clicking the screen and you can zoom out by right-clicking the screen. Click **OK** to apply the current settings to the Circuit Board block and close the Block Properties window.

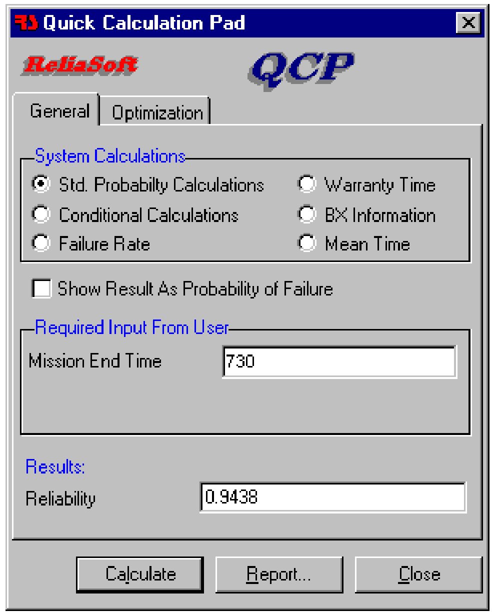
- The Circuit Board block has now been modified. It still contains the original picture, but it is now in the shape of a folder. Subdiagram blocks (blocks that contain subsystems or diagrams) are identified in BlockSim in this way.



The Circuit Board is now defined by the subsystem containing the Fan and Processor. In other words, the block definition indicates that the Circuit Board is composed of one Fan and one Processor. In reality, this is obviously not the case. However, this example simply shows you how one block can represent another diagram in BlockSim.

- To calculate the reliability of the system at 730 days, the QCP will be used. Select **Quick Calculation Pad** from the **Tools** menu or click the **QCP** icon.

- Select **Std. Probability Calculations** under System Calculations. Type **730** for the Mission End Time and click **Calculate**. The results are shown next.

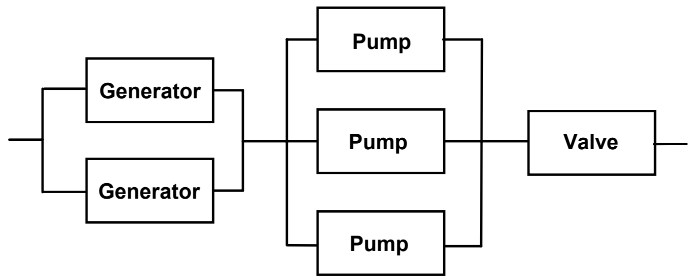


The reliability of the system at 730 days is 0.9438 (94.38%), which is the same as the result returned in Example 1.

- Save and close the project. You can close the project by selecting **Close Project** from the **File** menu or by right-clicking in the Project Explorer and selecting **Close Project** from the shortcut menu that appears.

4.1.4 Example 4

ACME Company manufactures subsystems for oil refinery plants. One of the subsystems that ACME manufactures consists of two Power Generators, three Pumps and one Valve. The two Generators are identical to each other, as are the Pumps. The Pumps are in a 2-out-of-3 configuration. The system configuration is shown next.



The following table presents the failure data for the Generators.

Number in Group	State	Time-to-failure, hr
1	F	1150
1	F	1660
1	S	1660
5	S	1850
2	F	3000
4	S	3000
1	S	3200
4	S	4150
1	F	4330
1	F	4800
4	S	4850
1	F	5600
1	F	6100
1	F	7800
3	S	8500
1	F	8750
2	S	8750
3	S	10100
1	S	11500
3	S	12000

The table shown next presents the failure distribution data and parameter values for the Pumps and the Valve.

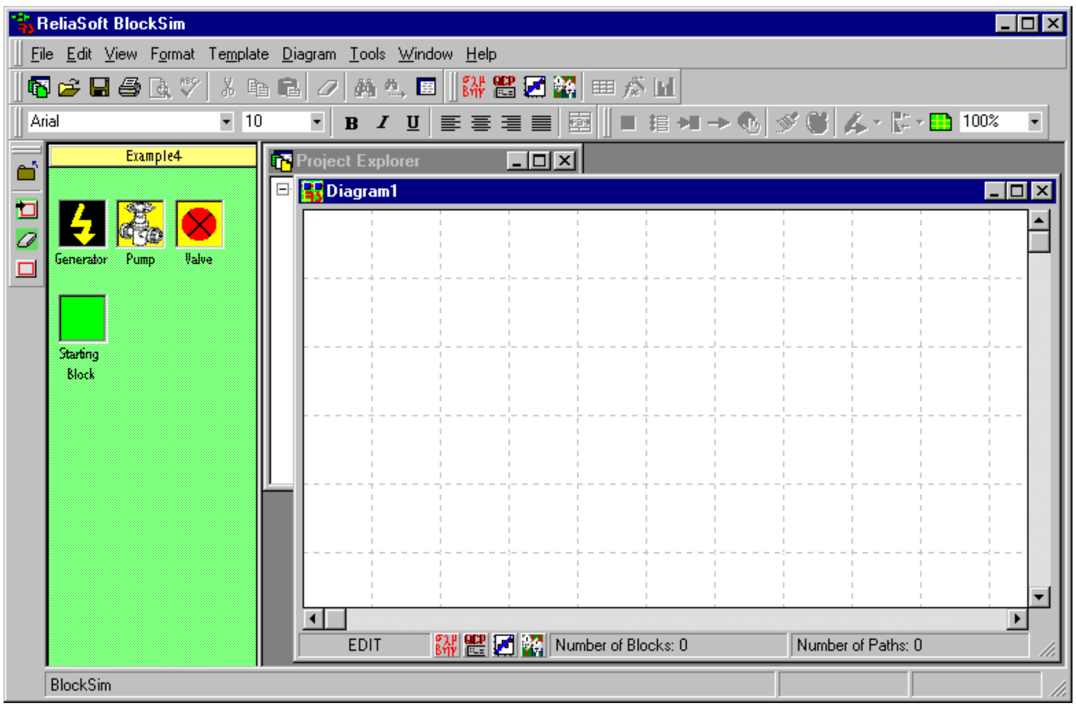
Component	Failure Distribution	Parameter Values
Pumps	Mixed Weibull (2 subpopulations)	β 1 = 0.589, η_1 = 6343.390 hrs, Portion[1] = 0.2695 β 2 = 2.394, η_1 = 20301.856 hrs, Portion[2] = 0.7305
Valve	Exponential	Mean Time = 830288.94

Do the following:

- Using the Weibull++ software, determine an appropriate failure distribution for the Generators based on the given data.
- Estimate the parameters of the selected distribution using maximum likelihood estimation (MLE).
- Generate a table of system reliabilities given a start time of 1000 hours and an end time of 5000 hours with a time increment of 1000 hours.

Solution

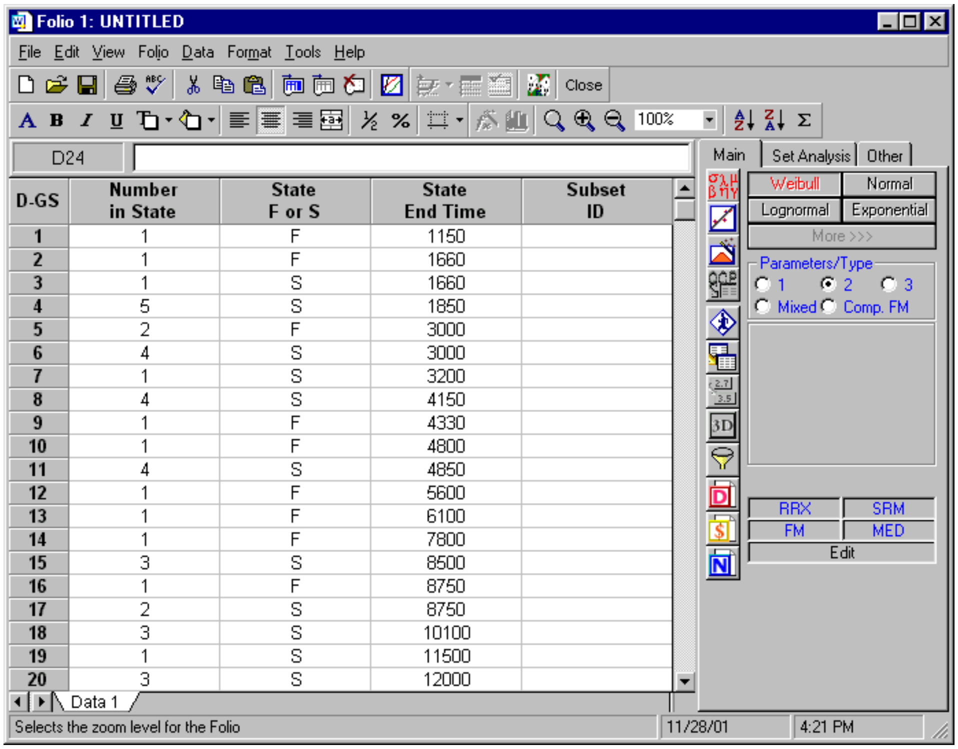
- Create a new project and select the **Example4.rst** template from the Template Preview window (in the BlockSim\Template directory) and click **Select**. The selected template will open in the new project.
- You will be prompted to enter a name for the new diagram sheet. Accept the default name. The Project Explorer and a blank diagram sheet will appear. Your screen will look like the picture shown next.



- Double-click the Generator block inside the Template Panel. The Block Properties window will appear. The properties for the Generator block have not been set. Although the parameter values are currently unknown, life data has been obtained based on life tests conducted on the Generator. This data, given in the table on page 40, can be used to calculate the parameters of the failure distribution for the Generator block.
- Be sure that you are on the Failure page of the Block Properties window. Click the **Compute Distribution** button in the bottom left corner. This will launch ReliaSoft's life data analysis software, Weibull++.[5] The version of Weibull++ that will appear (Weibull++ 5.0 or Weibull++ 6) will depend on which version was selected upon installation of the BlockSim software. The process for both versions is similar and this example uses Weibull++ 6.

5. Weibull++ must be installed on your computer in order for you to utilize the Compute Distribution option.

- Once Weibull++ has been activated, the Weibull++ Data Type Expert will appear.[6] You will use the Data Type Expert to create the appropriate Data Entry Spreadsheet for the Generator component's life data. In the Data Type Expert, click the **Times to Failure** button, the **with Right Censored Data (Suspensions)** button and the **with Grouped Observations** button. Click **OK**. A Data Entry Spreadsheet will be created for you based on your selections.
- Enter the data given for the Generator into the Data Entry Spreadsheet, as shown next.



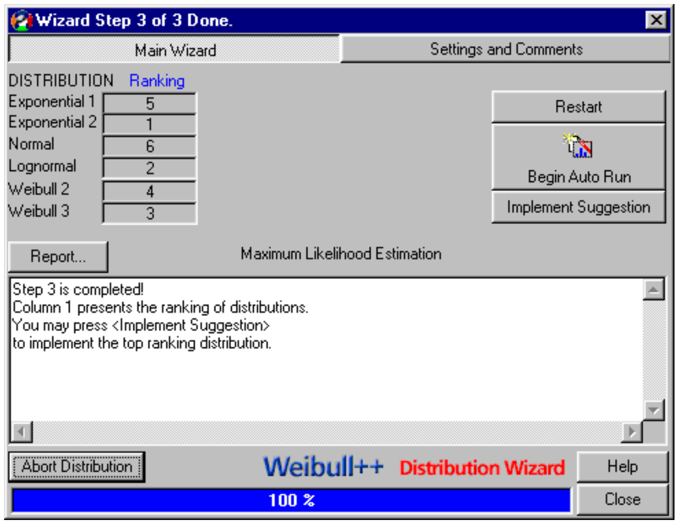
D-GS	Number in State	State F or S	State End Time	Subset ID
1	1	F	1150	
2	1	F	1660	
3	1	S	1660	
4	5	S	1850	
5	2	F	3000	
6	4	S	3000	
7	1	S	3200	
8	4	S	4150	
9	1	F	4330	
10	1	F	4800	
11	4	S	4850	
12	1	F	5600	
13	1	F	6100	
14	1	F	7800	
15	3	S	8500	
16	1	F	8750	
17	2	S	8750	
18	3	S	10100	
19	1	S	11500	
20	3	S	12000	

- Maximum likelihood estimation (MLE) will be used for the parameter estimation. You can specify this by clicking the **Set Analysis** tab on the Data Folio Control Panel. Select the **Maximum Likelihood (MLE)** option from the Analysis Method area. Return to the Main page of the Control Panel by clicking the **Main** tab.
- The Distribution Wizard utility in Weibull++ conducts a variety of goodness-of-fit tests designed to suggest the best distribution for your data. Select **Distribution Wizard** from the **Data** menu or click the **Distribution Wizard** icon.

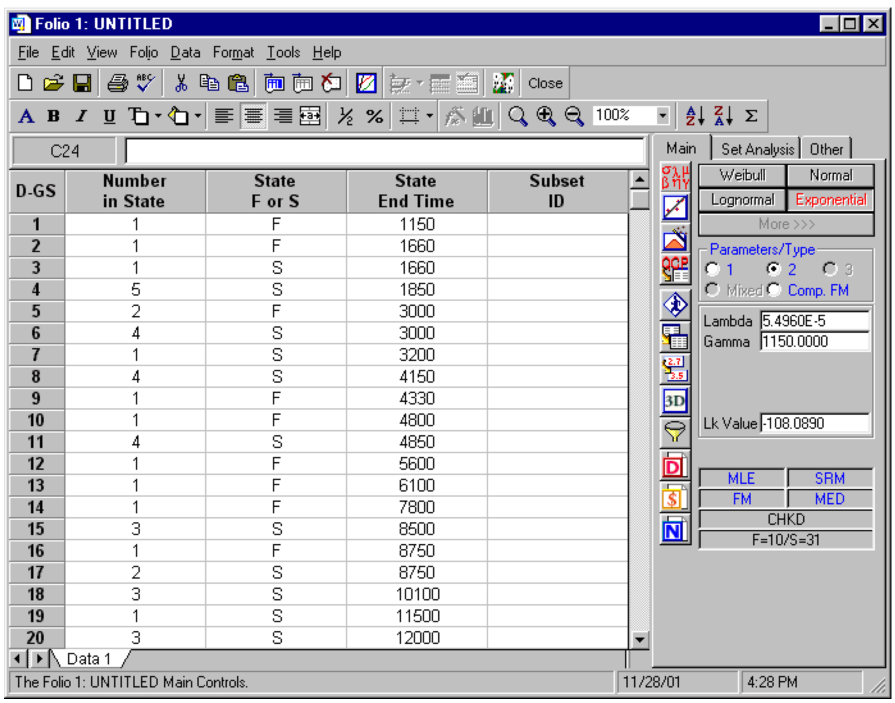
- The Distribution Wizard will appear. Click **Begin Auto Run** so that the Distribution Wizard can go through the process of suggesting a distribution. After the Distribution Wizard has finished conducting

[6] If the Data Type Wizard appears instead, click the **Data Type Expert** button to display the Data Type Expert.

the tests, the 2-parameter Exponential distribution will be suggested (indicated by the 1 in the Ranking column next to Exponential 2), as shown next.



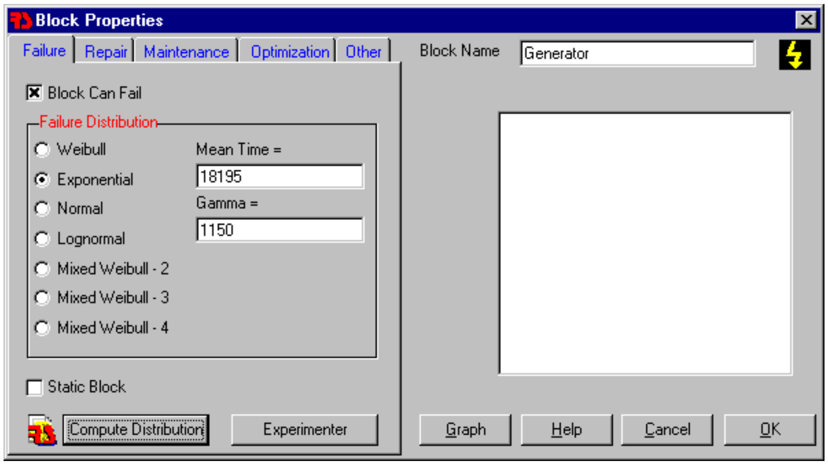
- Click **Implement Suggestion** to indicate that you would like to calculate the parameters using the 2-parameter Exponential distribution. The Distribution Wizard will close and you will now be viewing the Data Entry Spreadsheet with the entered data and the parameters calculated, as shown next.



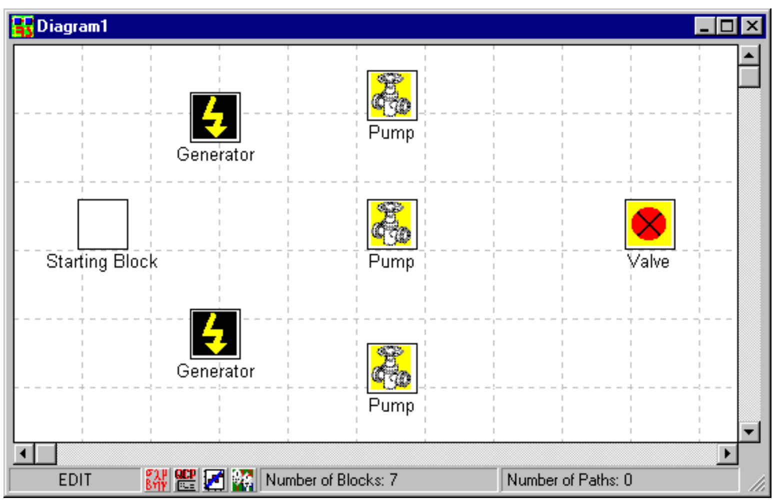
- Close Weibull++ by selecting **Close** from the **File** menu. A message box will appear to ask if you would like to save the changes made to the Data Folio. Click **Yes** and save the Data Folio as **Example4.rw6**. The next message box asks if you would like to update the block's distribution information. Click **Yes**.[7]

7. In Weibull++ 5, a third message box may appear to inform you that the failure distribution *pdf* plot cannot be displayed in the graphics screen on the right side of the Block Properties window because of insufficient resolution in the Y direction. Click **OK**.

- Notice that the parameter values that were calculated using Weibull++ have been inserted as the parameter values of the failure distribution of the Generator block, as shown next. Click **OK** to accept the current block properties.[8]



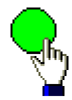
- Now you will arrange the blocks in the diagram. Because BlockSim's diagrams must have only one starting point, you will use the Starting block as the starting point of the diagram. Place the Starting block on the left side of the diagram. Drag one Generator block into the diagram and place it above and to the right of the Starting block. Drag another Generator block into the diagram and place it below and to the right of the Starting block. Drag the Pump block into the diagram three times, placing them in a vertical line to the right of the Generator blocks. Drag the Valve block into the diagram and place it on the far right side. Your diagram will look like the figure shown next.



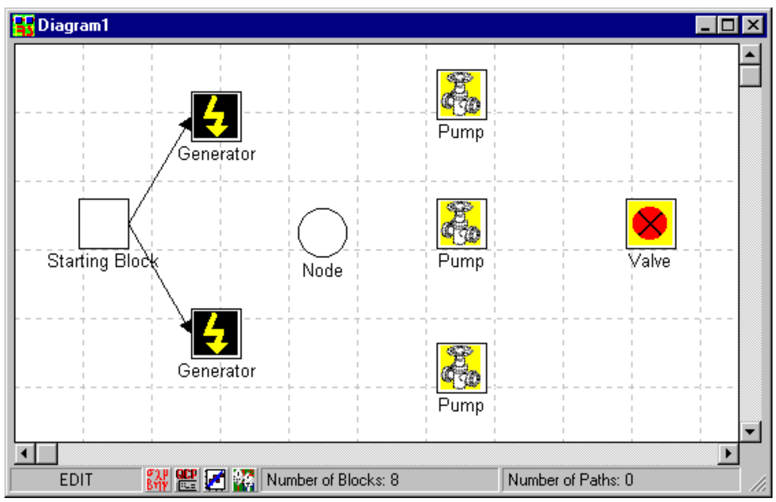
8. Note that because the Exponential parameter in BlockSim is defined by default as "Mean Time," the "Lambda" parameter calculated in Weibull++ was converted to "Mean Time" when you updated the block's distribution information. If "Lambda" had been defined as the Exponential parameter, the block properties would have been updated with the calculated Lambda value. You can change the Exponential parameter definition from the Calculations page of BlockSim's User Setup.

- Now you will connect the blocks by dragging relationship lines between them. Connect the starting block to each of the Generator blocks. The Generator blocks will be connected to each of the Pump blocks through a Node. A Node is a different type of block that can be defined to indicate the number of paths that must successfully pass through the block in order for the system to succeed (k-out-of-n). To place a node into the diagram, select **Add Node** from the **Diagram** menu or click the **Add Node** icon.

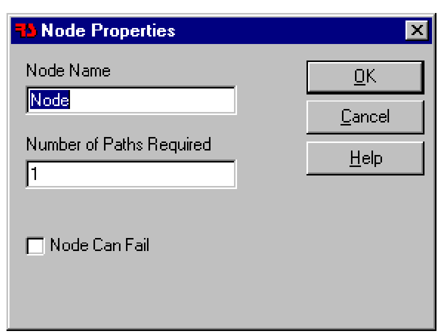
The cursor will turn into a pointing hand holding a circle.



- Place the cursor in the diagram between the Generator blocks and the Pump blocks and click to place the Node. Your screen will look like the figure shown next.

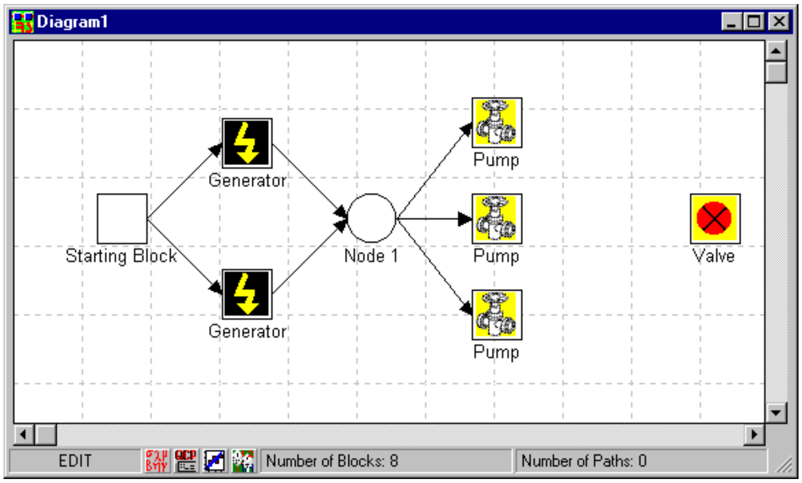


- Connect each Generator block to the Node. Connect the Node to each Pump block. Then double-click the Node to open the Node Properties window, shown next.

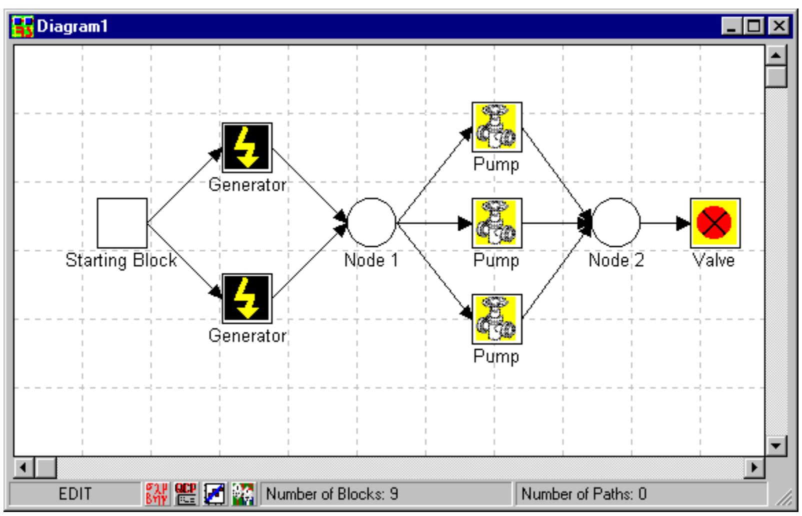


- In the Node Name input box, type **Node 1**. In the Number of Paths Required input box, type **1**, to indicate that one working Generator is required in order for the system to succeed. Make sure the **Node**

Can Fail option is not selected.[9] Click **OK** to close the Node Properties window. Your screen will look like the figure shown next.



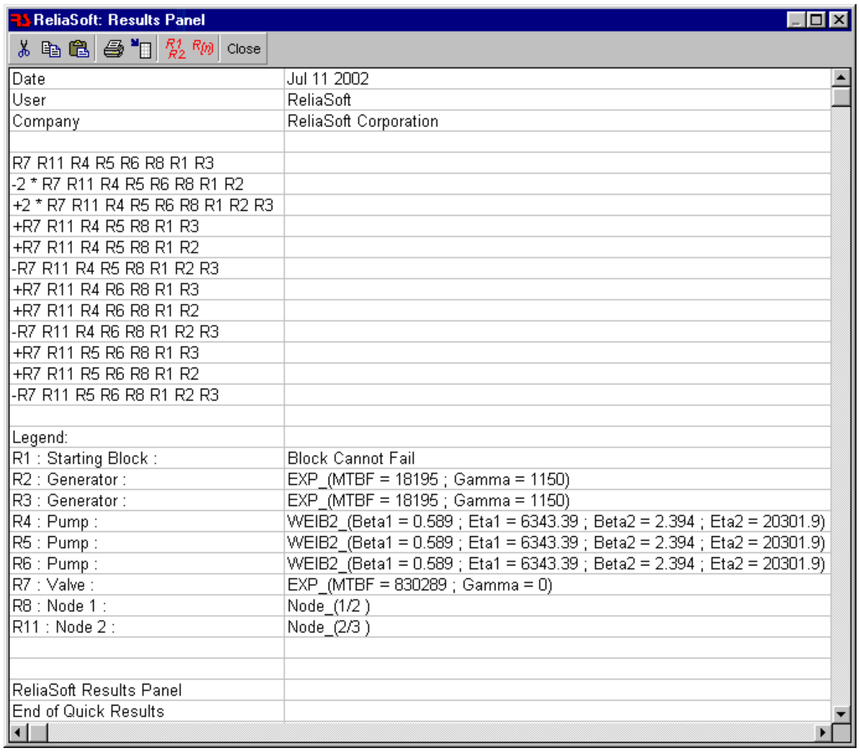
- You will also use a Node to represent the k-out-of-n configuration of the Pump blocks in relation to the Valve block. Place a Node between the Pump blocks and the Valve block. Double-click the Node to open the Node Properties window. In the Node Name box, type **Node 2**. In the Number of Paths Required box, type **2** to indicate that two working pumps are required in order for the system to operate. Make sure the **Node Can Fail** box is not selected. Click **OK** to close the Node Properties window.
- Now connect each Pump block to the Node 2 block and connect the Node 2 block to the Valve block. Your diagram will look like the figure shown next.



- Analyze the system by selecting **Analyze** from the **Tools** menu or by clicking the **Analyze** icon.

9. If the **Node Can Fail** box is selected, a Define Distribution button becomes available in the Node Properties window. Clicking the **Define Distribution** button opens a Block Properties window for the Node, where the failure and repair properties can be set for the Node.

- ReliaSoft's Results Panel will appear to display the results of the analysis, as shown next. Close the Results Panel by clicking **Close**.

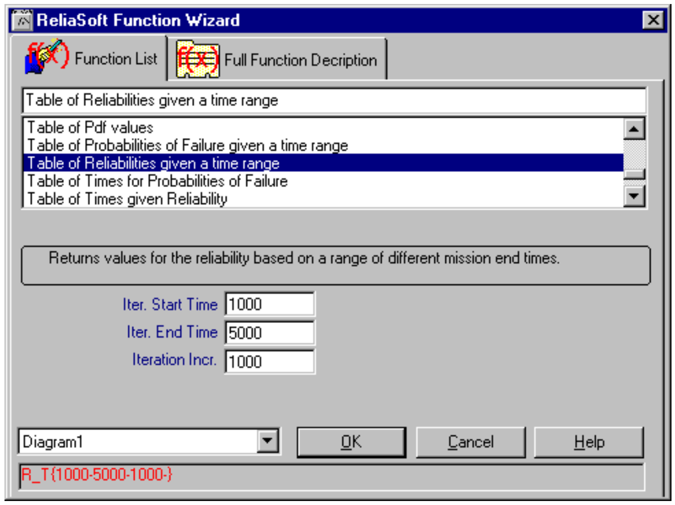


Date	Jul 11 2002
User	ReliaSoft
Company	ReliaSoft Corporation
R7 R11 R4 R5 R6 R8 R1 R3	
-2 * R7 R11 R4 R5 R6 R8 R1 R2	
+2 * R7 R11 R4 R5 R6 R8 R1 R2 R3	
+R7 R11 R4 R5 R8 R1 R3	
+R7 R11 R4 R5 R8 R1 R2	
-R7 R11 R4 R5 R8 R1 R2 R3	
+R7 R11 R4 R6 R8 R1 R3	
+R7 R11 R4 R6 R8 R1 R2	
-R7 R11 R4 R6 R8 R1 R2 R3	
+R7 R11 R5 R6 R8 R1 R3	
+R7 R11 R5 R6 R8 R1 R2	
-R7 R11 R5 R6 R8 R1 R2 R3	
Legend:	
R1 : Starting Block :	Block Cannot Fail
R2 : Generator :	EXP_(MTBF = 18195 ; Gamma = 1150)
R3 : Generator :	EXP_(MTBF = 18195 ; Gamma = 1150)
R4 : Pump :	WEIB2_(Beta1 = 0.589 ; Eta1 = 6343.39 ; Beta2 = 2.394 ; Eta2 = 20301.9)
R5 : Pump :	WEIB2_(Beta1 = 0.589 ; Eta1 = 6343.39 ; Beta2 = 2.394 ; Eta2 = 20301.9)
R6 : Pump :	WEIB2_(Beta1 = 0.589 ; Eta1 = 6343.39 ; Beta2 = 2.394 ; Eta2 = 20301.9)
R7 : Valve :	EXP_(MTBF = 830289 ; Gamma = 0)
R8 : Node 1 :	Node_(1/2)
R11 : Node 2 :	Node_(2/3)
ReliaSoft Results Panel	
End of Quick Results	

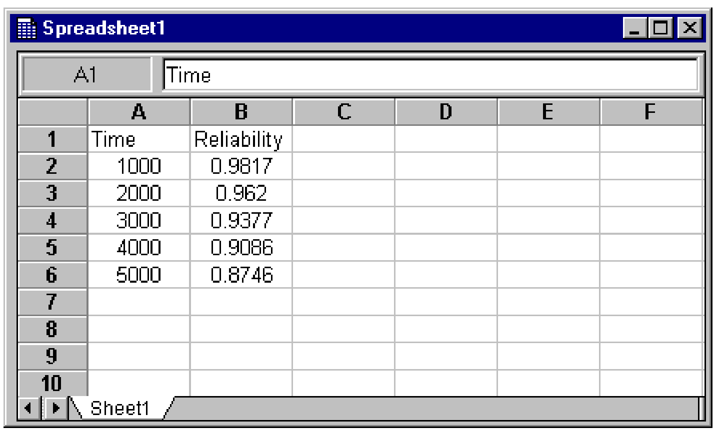
- Insert a spreadsheet into the project by selecting **Add New File** from the **File** menu and then selecting **Add New Spreadsheet**. A spreadsheet will open in the MDI. You can also see that the spreadsheet has been added to the project in the Project Explorer.
- Return the focus to Spreadsheet 1. The Function Wizard will be used to generate a table of system reliabilities. Open the Function Wizard by selecting **Function Wizard** from the **Tools** menu or by clicking the **Function Wizard** icon.

The diagram sheet to which the Function Wizard is linked (in this case, Diagram 1) is displayed in the drop-down menu in the bottom left corner. The Function Wizard is linked to the diagram sheet that is active when the Function Wizard is activated.

- Scroll through the list of available functions and select **Table of Reliabilities given a time range**. Type **1000** for the Iter. Start Time, **5000** for the Iter. End Time and **1000** for the Iteration Incr. in the input boxes, as shown next.



- Click **OK** to generate the table in the spreadsheet. The generated table is shown in the next figure.

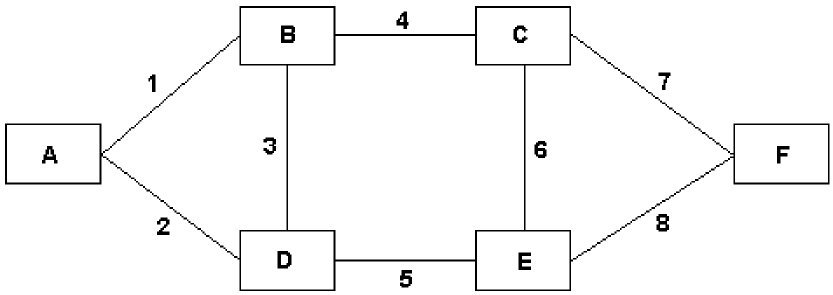


	A	B	C	D	E	F
1	Time	Reliability				
2	1000	0.9817				
3	2000	0.962				
4	3000	0.9377				
5	4000	0.9086				
6	5000	0.8746				
7						
8						
9						
10						

- Save the project as **Example4.rsw** and close the project.

4.1.5 Example 5

Consider the following telecommunications network:



The letters A-E represent the communication centers, where A is the main center. F is a city to which service is being supplied. The numbers 1-8 represent the communication lines. Communication lines 3 and 6 can operate in two directions, *e.g.* from B to D and from D to B. The communication centers cannot fail, while the failure rate (λ) for the communication lines is 1.3E-6 failures/hour. The repair distribution for the communication lines is normal with a mean time of 101.35 hours and a standard deviation of 62.1 hours.

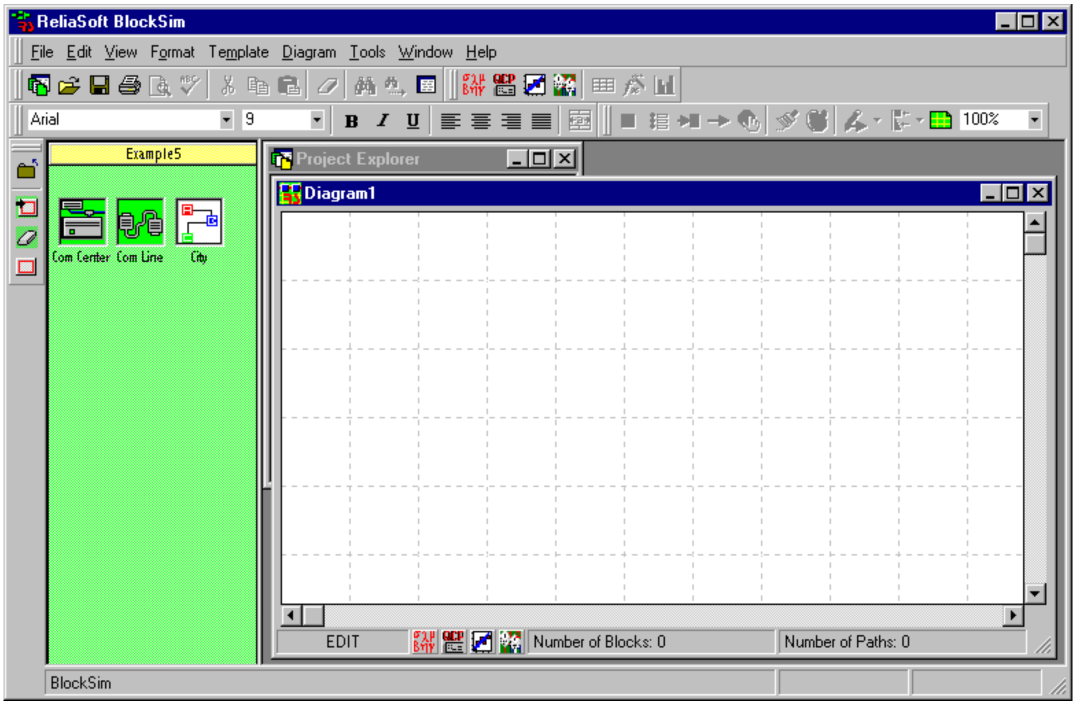
Do the following:

- Find the reliability of the system at 17,520 hours.
- Find the estimated time at which 25% of the communication systems that are in operation will have failed.
- Using the Reliability/Maintainability Simulation window, estimate the total downtime for the system for one year (8,766 hours).
- Add this system to a template so that the entire system can be added to a national communications system.

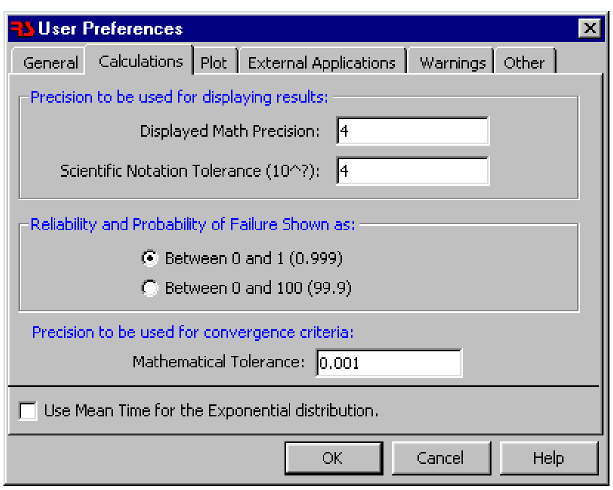
Solution

- Create a new project by selecting **New Project** from the **File** menu or by clicking the **New Project** icon.

- Select the **Example5.rst** template from the Template Preview window and click **Select**. The selected template will open in the new project. When you are prompted to enter a name for the new diagram sheet, accept the default name. The Project Explorer and a blank diagram sheet will also appear. Your screen will look like the picture shown next.



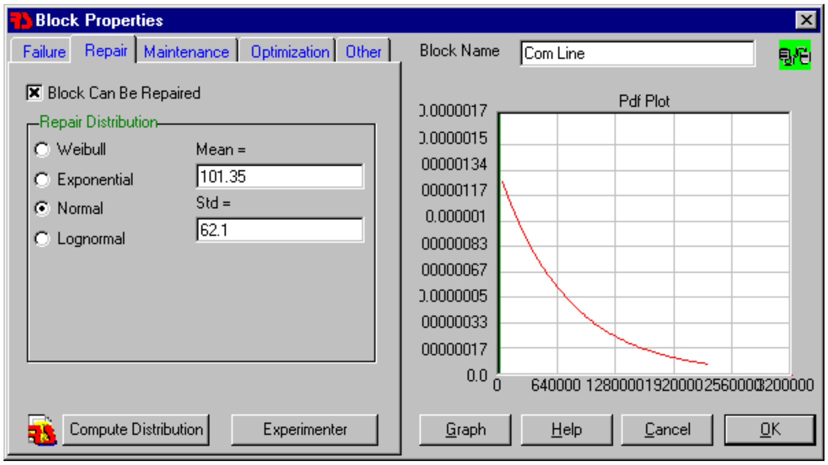
- For this example, the Exponential parameter will be defined as "Lambda" instead of "Mean Time." To define the Exponential parameter as Lambda, select **User Setup** from the **File** menu to open the User Setup window. Click the **Calculations** tab to display the Calculations page of the User Setup and de-select the **Use Mean Time for the Exponential distribution** option at the bottom of the window, as shown next.



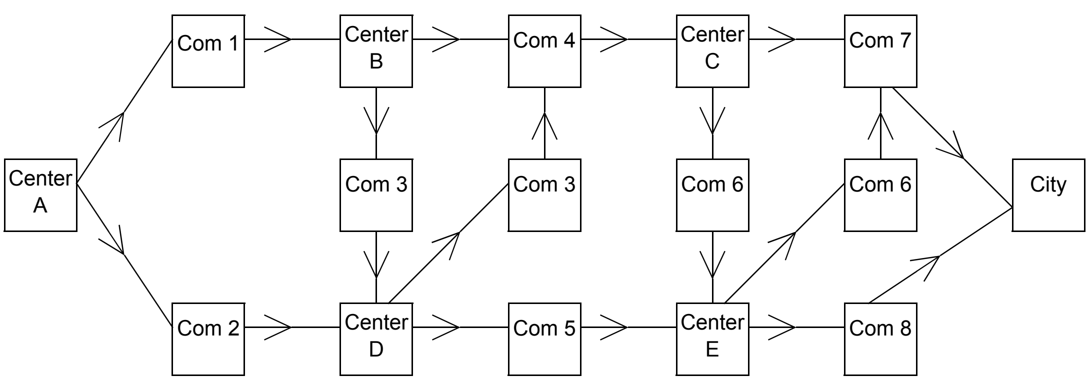
When the **Use Mean Time for the Exponential distribution** option is not selected, you will be prompted to enter a value for lambda each time you define a block with the exponential distribution.

- Click **OK** to close the User Setup window.
- Double-click the Com Center block in the template to open the Block Properties window. The Com Centers designated by the letters A-E cannot fail. Therefore, make sure the **Block Can Fail** option is not selected and click **OK**.

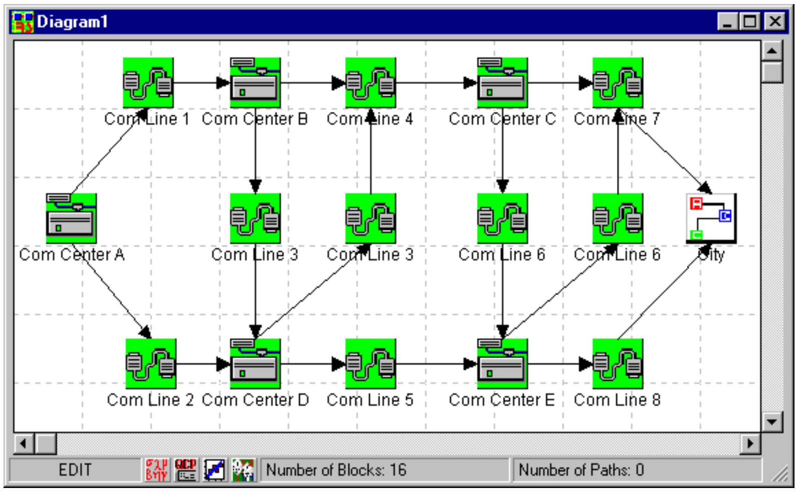
- Now double-click the Com Line block. The failure distribution associated with each Communication Line is the Exponential distribution. Select **Exponential** under Failure Distribution. Enter **1.3E-6** for the value of Lambda and **0** for the value of Gamma.
- Click the **Repair** tab to open the Repair page of the Block Properties window. Click to select the **Block Can Be Repaired** option. The Repair Distribution options will become available. Select **Normal** as the repair distribution and enter **101.35** for the Mean value and **62.1** for the Std value, as shown next.



- Click **OK** to accept the block properties and close the window. Finally, double-click the City block. As is the case for the Com Centers, the City cannot fail. Click to de-select the **Block Can Fail** option and click **OK**.
- The Communication Lines are the most important blocks in this example. The Communication Centers cannot fail and will be used as Nodes within the RBD. They will be used to direct the Communication Lines. In addition, because Lines 3 and 6 flow in two directions, multiple representations of Lines 3 and 6 and Communication Centers B-E must be included. A relationship line within BlockSim cannot flow in two directions at the same time. In other words, there can be no circular paths. When constructing the RBD, be sure to change the name of each Com Line and Com Center block within the diagram to represent the proper Communication Line. You can change the name of the block by double-clicking it to open the Block Properties window. The Block Name input box is in the upper right corner. Designate each Communication Line as Com 1, Com 2, etc. Designate each Communication Center as Com A, Com B, etc. A representation of the RBD to be constructed is shown next.



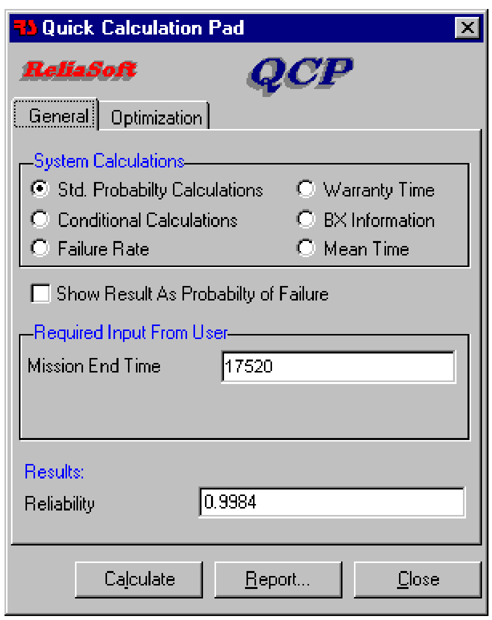
- The RBD constructed using BlockSim is shown next.



- Analyze the system by selecting **Analyze** from the **Tools** menu or by clicking the **Analyze** icon.

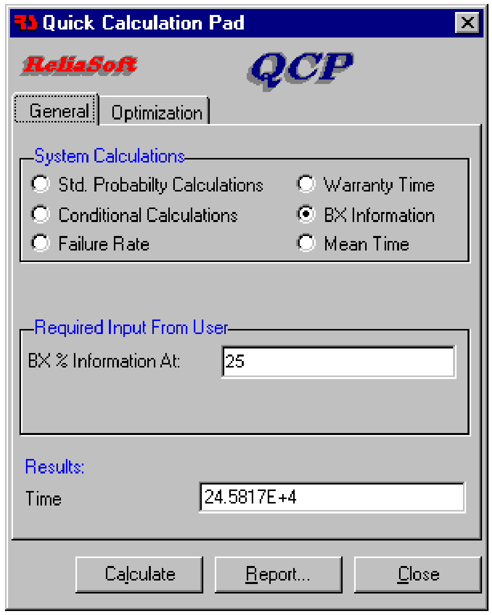
- ReliaSoft's Results Panel will appear, displaying the results of the analysis. Click **Close** to close the window.
- The Quick Calculation Pad (QCP) will be used to calculate the reliability of the system. To access the QCP, select **Quick Calculation Pad** from the **Tools** menu or click the **QCP** icon.

- Select **Std. Probability Calculations** under System Calculations. Type **17520** for the Mission End Time and click **Calculate** to return the system reliability, as shown next.



The reliability of the system at 17,520 hours is 0.9984 (99.84%).

- The second question requires the time at which 25% of the communication systems in operation will have failed. Select **BX Information** under System Calculations. Type **25** in the BX% Information At input box and click **Calculate** to return the result, as shown next.

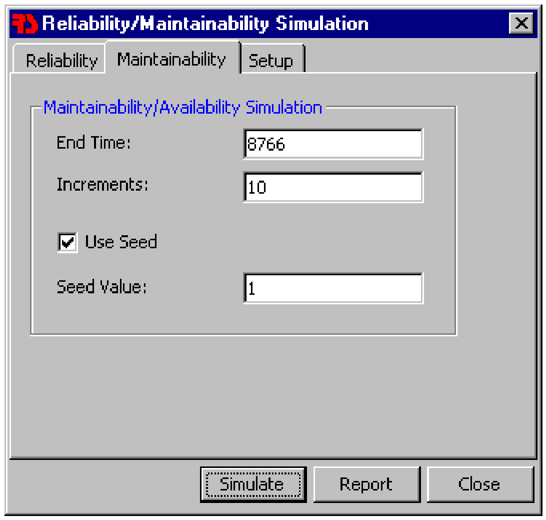


The time at which 25% of the communication systems will fail is approximately 24.5817E+4 hours.

- Close the QCP by clicking **Close**.

- You will now use BlockSim's Reliability/Maintainability Simulation utility to analyze the system for one year of operation.[10] Select **Simulate** from the **Tools** menu or click the **Simulate** icon.

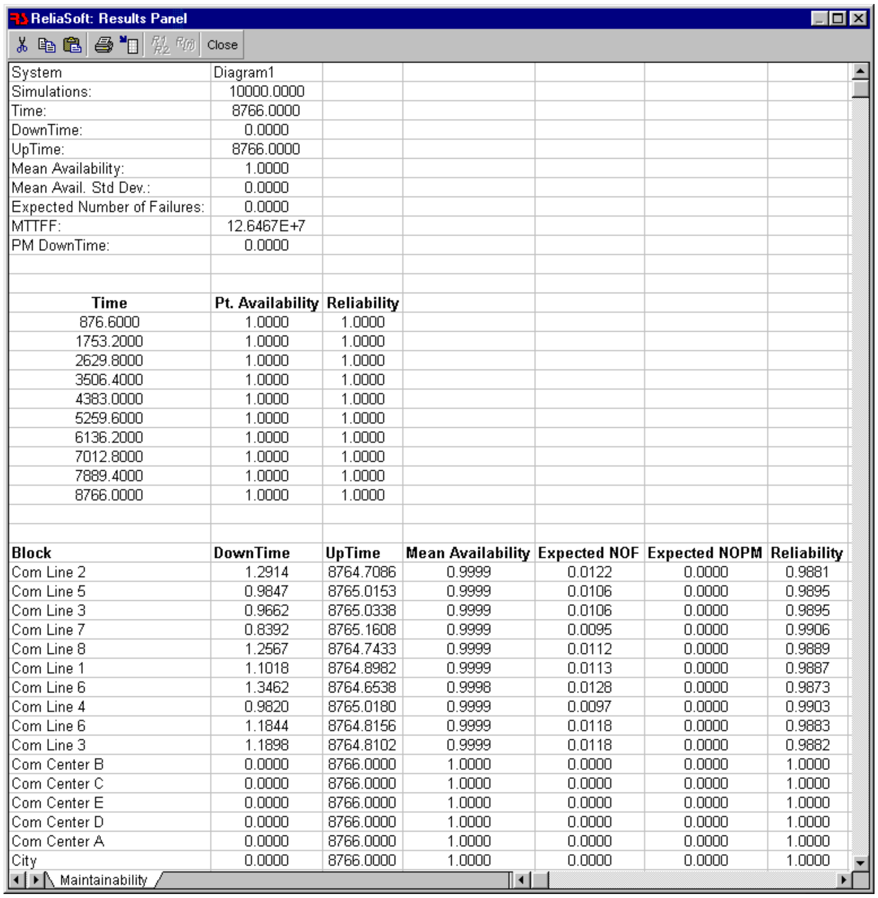
- The Reliability/Maintainability Simulation window will open. Click the **Maintainability** tab to open the Maintainability page.
- On the Maintainability page, type **8766** in the End Time field. Type **10** in the Increments field, which allows you to specify the maximum number of iterations of the optimization algorithm to be conducted in order to obtain a solution. Select the **Use Seed** option and input a Seed Value of **1**. Using a seed for the simulation allows you to replicate these results. The window will look like the figure shown next.



- Click the **Setup** tab to access the Setup page. Type **10000** in the Number of Simulations input box, which allows you to specify the number of simulations to be performed to obtain a solution. Return to the Maintainability page of the window and click **Simulate** to begin the simulation.

10. The calculations performed in the QCP are based only on the failure information of the components. The Reliability/Maintainability Simulation utility uses the repair information of the components in order to obtain such results as point availability, mean availability, etc.

- The results will be displayed in ReliaSoft's Results Panel, as shown next.



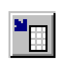
System	Diagram1
Simulations:	10000.0000
Time:	8766.0000
DownTime:	0.0000
UpTime:	8766.0000
Mean Availability:	1.0000
Mean Avail. Std Dev.:	0.0000
Expected Number of Failures:	0.0000
MTTFF:	12.6467E+7
PM DownTime:	0.0000

Time	Pt. Availability	Reliability
876.6000	1.0000	1.0000
1753.2000	1.0000	1.0000
2629.8000	1.0000	1.0000
3506.4000	1.0000	1.0000
4383.0000	1.0000	1.0000
5259.6000	1.0000	1.0000
6136.2000	1.0000	1.0000
7012.8000	1.0000	1.0000
7889.4000	1.0000	1.0000
8766.0000	1.0000	1.0000

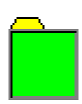
Block	DownTime	UpTime	Mean Availability	Expected NOF	Expected NOPM	Reliability
Com Line 2	1.2914	8764.7086	0.9999	0.0122	0.0000	0.9881
Com Line 5	0.9847	8765.0153	0.9999	0.0106	0.0000	0.9895
Com Line 3	0.9662	8765.0338	0.9999	0.0106	0.0000	0.9895
Com Line 7	0.8392	8765.1608	0.9999	0.0095	0.0000	0.9906
Com Line 8	1.2567	8764.7433	0.9999	0.0112	0.0000	0.9889
Com Line 1	1.1018	8764.8982	0.9999	0.0113	0.0000	0.9887
Com Line 6	1.3462	8764.6538	0.9998	0.0128	0.0000	0.9873
Com Line 4	0.9820	8765.0180	0.9999	0.0097	0.0000	0.9903
Com Line 6	1.1844	8764.8156	0.9999	0.0118	0.0000	0.9883
Com Line 3	1.1898	8764.8102	0.9999	0.0118	0.0000	0.9882
Com Center B	0.0000	8766.0000	1.0000	0.0000	0.0000	1.0000
Com Center C	0.0000	8766.0000	1.0000	0.0000	0.0000	1.0000
Com Center E	0.0000	8766.0000	1.0000	0.0000	0.0000	1.0000
Com Center D	0.0000	8766.0000	1.0000	0.0000	0.0000	1.0000
Com Center A	0.0000	8766.0000	1.0000	0.0000	0.0000	1.0000
City	0.0000	8766.0000	1.0000	0.0000	0.0000	1.0000

As you can see, the down time for the system is 0 hours of the 8766 total hours.

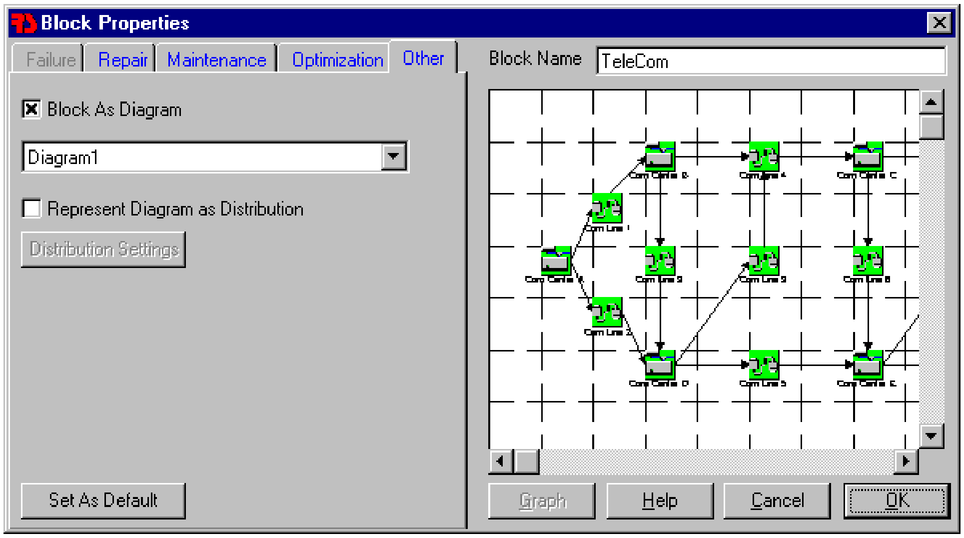
- These results can be sent to a spreadsheet by clicking the **Transfer to Spreadsheet** icon.



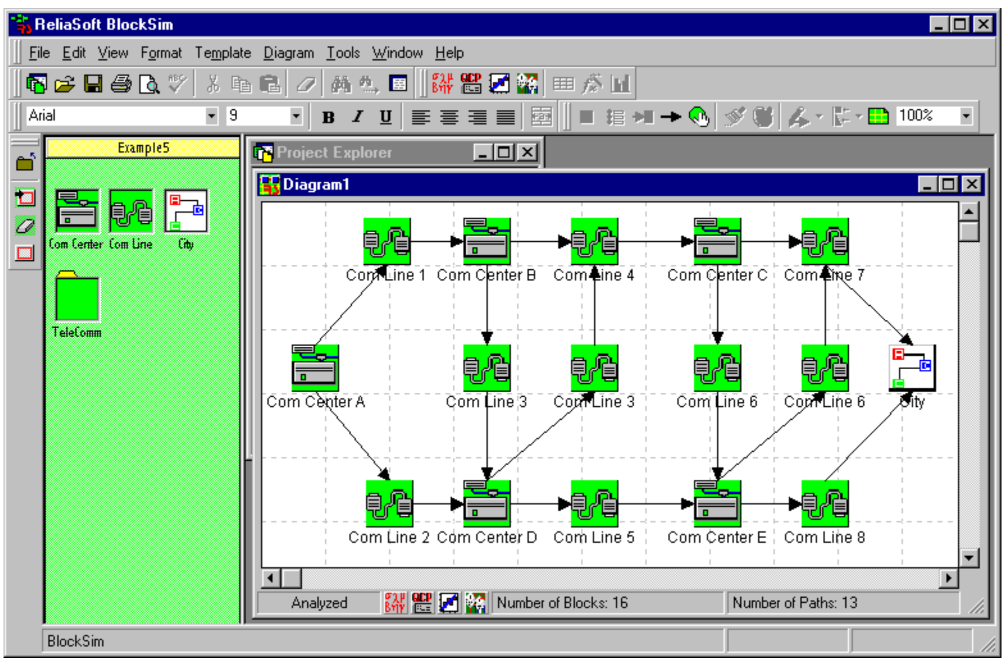
- When you are prompted to enter a name for the new spreadsheet, accept the default name.
- Close the Result Panel and the Reliability/Maintainability Simulation window. You can see that the spreadsheet has been added to the project in the Project Explorer.
- BlockSim also allows you to add entire diagrams to templates. This makes it possible to represent an entire system with one block and to re-use that block in multiple diagrams and/or projects. To add the current system to the Example5 template, first save the project as **Example5.rsw**. Then right-click the diagram sheet and select **Add Diagram to Template** from the shortcut menu that appears. BlockSim will automatically save the diagram and a subdiagram block will appear within the Example5 Template Panel just below the other blocks, identified by the folder graphic, as shown next.



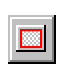
- Double-click the newly created subdiagram block to open the Block Properties window. On the Other page, select **Block As Diagram**. The system will be displayed in the graphics screen on the right. Type **TeleComm** in the Block Name input box, as shown next.



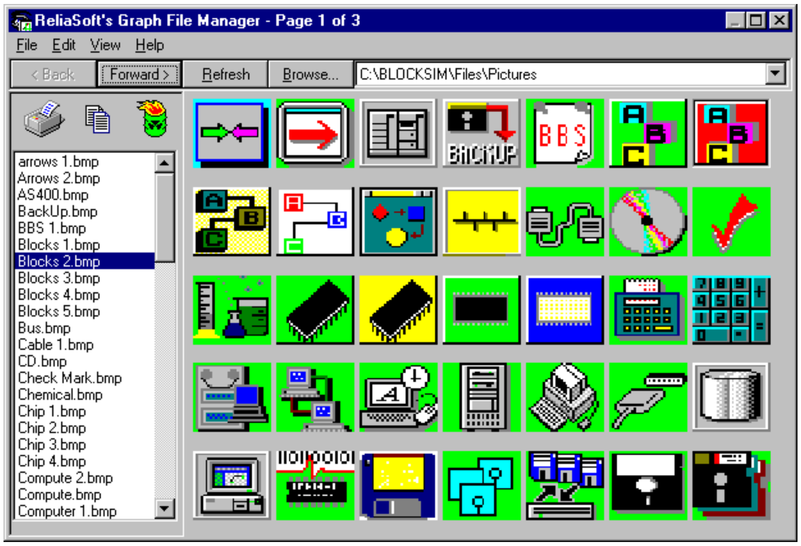
- Click **OK** to close the Block Properties window. As you can see, the block name Diagram1 has been renamed to TeleComm, as shown next.



- Finally, the block can be represented with a picture, if desired. Select the Telecomm block and click the **Block Graphic** icon.



- The Graph File Manager will open to allow you to select a bitmap graphic (*.bmp) for display on the block, as shown next. (Please note that the appearance of the Graph File Manager will depend on the directory that is opened in the Graph File Manager.)



The Graph File Manager allows you to preview previously saved bitmap (*.bmp) graphics that can be used to display on BlockSim blocks. To use the Graph File Manager, use the **Browse** button and/or drop-down menu at the top of the window to select a directory that contains (*.bmp) files. A preview of each graphic in the directory will appear in the preview area. The filename for each (*.bmp) file in the selected directory is displayed in the filename box on the left side of the window. You can select a filename or preview image and then select **Select Graphic** from the **File** menu to display a graphic on the current block. You can also double-click a file name or preview image to display it on the current BlockSim block.

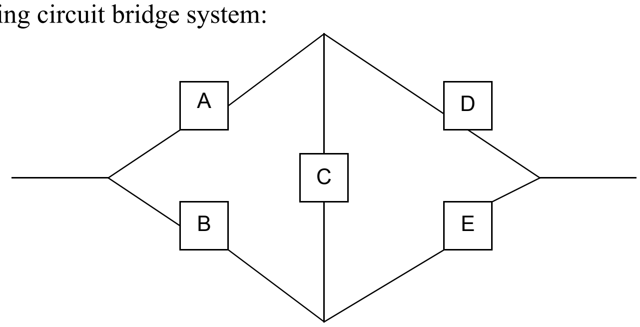
- Select a picture from the list and select **Select Graphic** from the **File** menu to represent the system within the block.
- You can now close the project. The Save Changes window will appear, prompting you to save the files to which you have made changes. Make sure that all files in the Save Changes window are selected and click **Yes**. The Telecomm block can now be inserted into another completely separate diagram if necessary. The subdiagram block now represents the entire system that was created during this example.

5 Practice Questions

The following practice questions can be performed using BlockSim. The answers to these practice questions can be found in Chapter 6.

5.1 Practice Question 1

Consider the following circuit bridge system:



All components are identical, following an exponential life distribution with λ = 8.126E-4 failures/day.

1. Create a template to create the RBD and customize the template to your liking.
2. Create the reliability block diagram for this system.
3. Estimate the reliability at 200 days using the QCP.
4. Create the Reliability vs. Time plot.
5. Insert the Reliability vs. Time plot into the project.
6. Rename the diagram as “Bridge System.”
7. Export the diagram as “Bridge System.rsb.”

8. Save your project as "QUEST1.RSW" and leave it open.

5.2 Practice Question 2

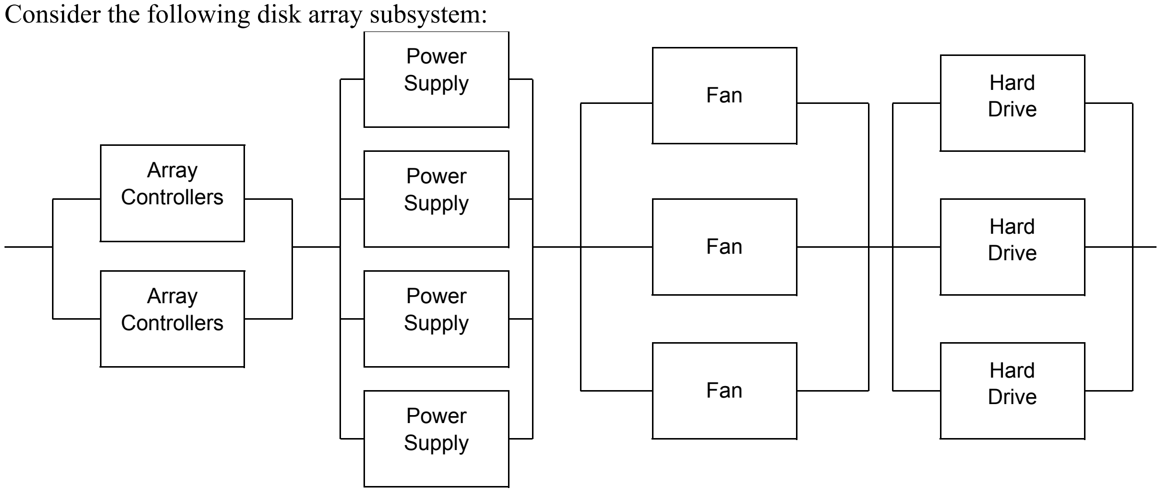
The reliability predictions of Practice Question 1 can also be performed using simulation. However, the results are dependent on the number of simulations. This example will take you through such a scenario.

1. QUEST1.RSW will already be open.
2. Open the Reliability/Maintainability Simulation window by clicking its icon.

3. On the Reliability page, enter an End Time of **200** and an Increments value of **100**.
4. On the Setup page, type **100** for the Number of Simulations. Return to the Reliability page and click **Simulate** to perform the simulation. What is the reliability of the system at 200 days? How does this value compare with the reliability obtained in Practice Question 1?
5. Repeat step 4 with 1000, 5000 and 10000 simulations. When is the reliability estimate closer to the analytical value obtained in Practice Question 1?
6. Save and close the project.

5.3 Practice Question 3

Consider the following disk array subsystem:



The failure distributions and parameters for each component are:

Component	Distribution	Parameters
Array Controllers	Weibull	β = 1.2, η = 1953 days.
Power Supply	Lognormal	μ = 7.0102 (log-mean), σ = 1.2124 (log-std).
Fan	Exponential	λ = 0.000070265 failures/day.
Hard Drive	Weibull	β = 2.5, η = 3000 days.

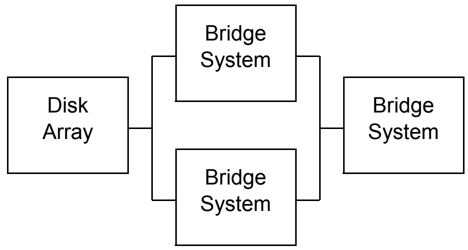
The Power Supply subsystem is in a 2-out-of-4 configuration. The Fans are in a 2-out-of-3 configuration. The Hard Drives are also in a 2-out-of-3 configuration.

Do the following:

1. Create a block for each type of component within a template and customize the template to your liking.
2. Create the RBD and rename the diagram to “Disk Array.”
3. Obtain the Reliability vs. Time plot.
4. From the plot, determine:
   i. The reliability of these units for a mission of 182 days, R(182days).
   ii. The mission duration for the system if a 90% reliability is required.
5. Add the plot to the project.
6. Using the Quick Calculation Pad, determine:
   i. The reliability of the system for a mission of 182 days, R(182days).
   ii. The reliability for each subsystem/component.
   iii. The mission duration for the system if a 90% reliability is required.
   iv. Knowing that the system has successfully operated for 182 days, what is the probability that it will operate successfully for another 182 days?
   v. What is the MTTF for the system?
7. Obtain the *pdf* plot for the system.
8. Obtain the Failure Rate vs. Time plot for these units. From the plot, what is the failure rate of the system at 182 days?
9. Add a spreadsheet into the project. Using the Function Wizard, obtain:
   i. The failure rate at 182 days.
   ii. A table of times given reliability, starting from 0.9 to 0.99 with a 0.01 increment.
10. Export the diagram as “Disk Array.rsb.”
11. Break the system into 4 subsystems by creating 4 new diagrams: an Array Controllers diagram, a Power Supplies diagram, a Fans diagram and a Hard Drives diagram.
    i. Add a new template to the project.
    ii. Add each of the 4 new subdiagrams to the new template.
    iii. Create the RBD for the system using the subdiagrams.
    iv. Using the QCP, obtain the reliability of this system for a mission of 730 days, R(730days).
    v. A reliability goal of 85% is required at 730 days (2 years). Is the reliability goal met? If not, optimize the system if it is known that there is only room for improvement for the two Array Controllers and the Power Supplies. In addition, it is known that it is hard to improve the Array Controllers and much easier to improve the Power Supplies. The maximum achievable reliability is 0.999 for both subsystems.
    vi. Using the optimum reliability values obtained for the Array Controllers subsystem and for the Power Supplies subsystem, determine the optimum reliability values at the component level for these two subsystems. (Hint: Use the subdiagrams.)
12. Save your file as “QUEST3.RSW.”
13. Close the project.

5.4 Practice Question 4

This example shows how you can import previously created diagrams and use them as components in a new diagram. Consider the following system in which the Disk Array of Practice Question 3 is connected with the Bridge System of Practice Question 1, as shown next:



1. Create a new project.
2. Import the previously saved diagrams: Bridge System.rsb and Disk Array.rsb.
3. Create the RBD for the system shown above where the blocks represent the corresponding Disk Array and Bridge System diagrams that were imported.
4. Estimate the reliability of the system at 200 days.
5. Save the project as “QUEST4.RSW” and close it.

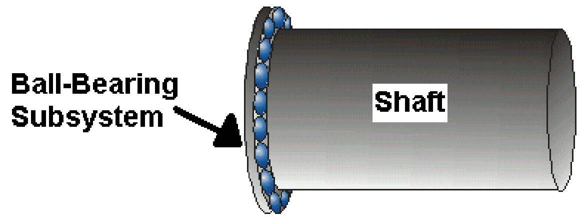
5.5 Practice Question 5

A four-engine airplane has two engines on each wing. It requires at least one engine to be operating on each wing for a successful mission. Assume that the reliability of each engine is 90% for a specified mission duration.

1. Create the RBD.
2. Obtain the reliability of the system.
3. Add a new diagram and repeat the example, but this time consider a 2-out-of-4 engine configuration.
4. When is the reliability of the system higher? Why?
5. What would the reliability of each engine be in the first design in order to achieve the system reliability of the second design? Since the units are identical, you can assume the same feasibility of increasing the reliability and maximum achievable reliability for each engine.
6. Save the project as “QUEST5.RSW” and close it.

5.6 Practice Question 6

A subsystem of a machine is composed of a Ball-Bearing subsystem and a Shaft, as shown below:



The inspection times (in hours) for the Ball-Bearing subsystem are given in the table below.

Number in State	Last Inspected	State	State End Time
5	0	F	600
16	600	F	1900
12	1900	F	2900
18	2900	F	3500
18	3500	F	3900
2	3900	F	4500
6	4500	F	5200
17	5200	F	6300
73	6300	S	6300

The life data set for the Shaft is given in the table below.

Number in State	State	State End Time
1	F	1226
1	F	1943
1	F	2362
1	F	2518
1	F	5462
1	F	6404
1	F	10388
5	S	11772

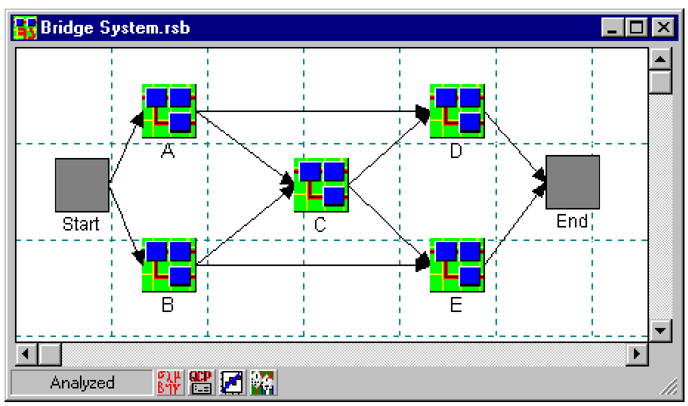
1. Using the 2-parameter Weibull distribution for the Ball-Bearing data and the Lognormal distribution for the Shaft data, estimate the reliability of the system at 1,000 hrs.
2. What is the reliability of each component at 1,000 hrs?

6 Answers to Practice Questions

The purpose of this section is to provide answers to the Practice Questions in Chapter 5.

6.1 Practice Question 1

2.



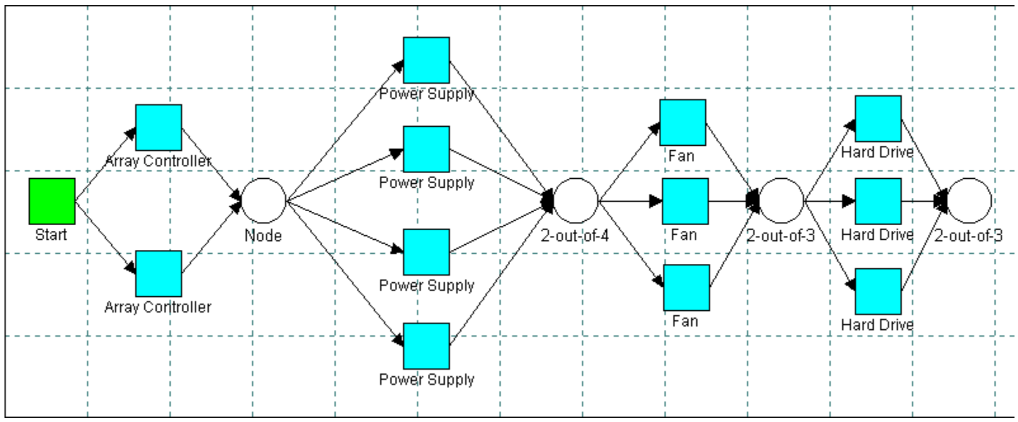
3. R(200days) = 0.9506

6.2 Practice Question 2

4. R(200days) = 0.9400. Not very accurate.
5. The reliability estimated using 100,000 simulations is closer to the analytical value.

6.3 Practice Question 3

2.

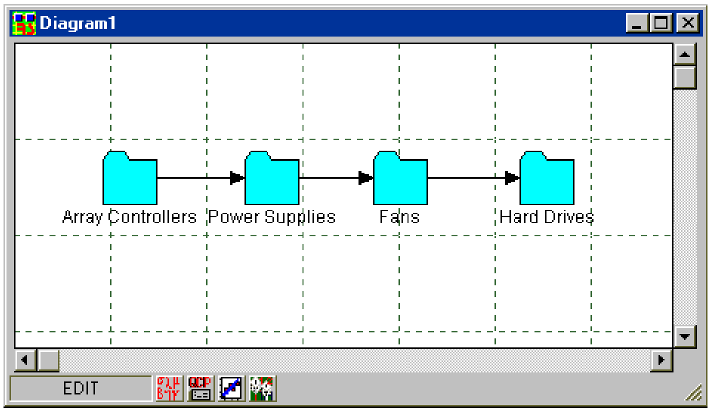


4. From the Reliability vs. Time plot:
   i. R(182days) ≅ 0.99
   ii. T ≅ 530 days
6. Using the QCP:
   i. R(182days) = 0.9951
   ii. Array Controller: 0.9437
   Power Supply: 0.9319
   Fan: 0.9873
   Hard Drive: 0.9991
   iii. T = 527.6891
   iv. R(182,182) = 0.9676
   v. MTTF = 1316.1014 days
8. $\lambda \approx 0.00008$ failures/day
9. Using the Function Wizard:
   i. λ = 7.70425E-005 failures/day
   ii.

Reliability	Time
0.9	527.6891
0.91	505.9283
0.92	483.1063
0.93	458.9627
0.94	433.1295
0.95	405.0584
0.96	373.8714
0.97	338.0091
0.98	294.1975
0.99	232.9436

11.

iii.



iv. R(730days) = 0.7906

v. Array Controller: 0.9301 (no change)
Power Supplies: 0.9228

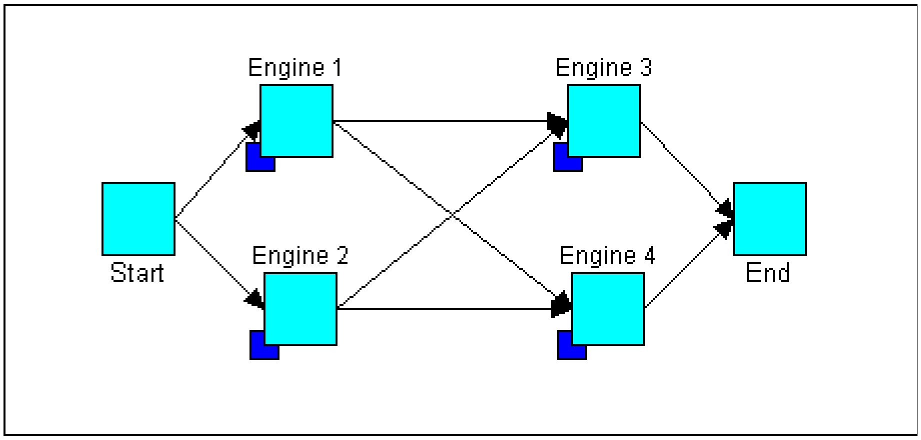
vi. Array Controller: No change
Power Supplies: 0.7088

6.4 Practice Question 4

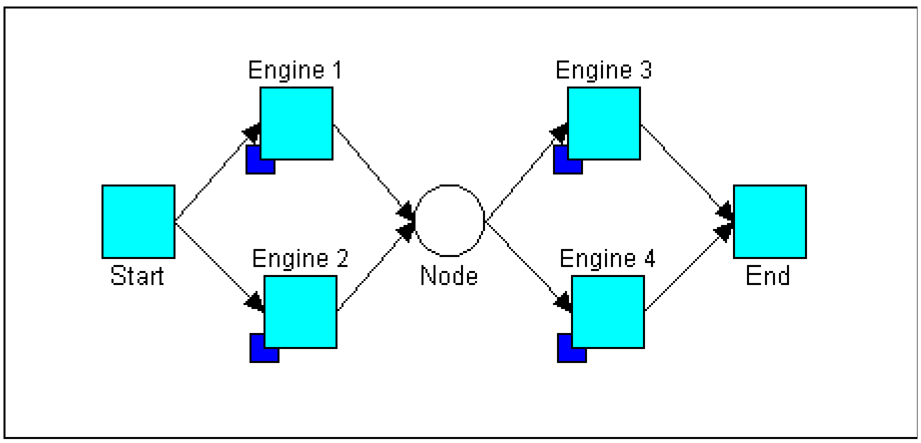
4. R(200days) = 0.9423

6.5 Practice Question 5

1.



Or



2. R = 0.9801
3. For the 2-out-of-4 engine configuration: R = 0.9963
4. The second design, because there is more redundancy in the 2-out-of-4 configuration.
5. The reliability for each engine is: R = 0.957

6.6 Practice Question 6

1. R(1000hrs) = 0.8999
2. Bearings: 0.944841

   Shaft: 0.952387