

THE
SYNTHESIS[®]
PLATFORM

Use with: Synthesis10_Guide_Rev1.rsgz10

THE
SYNTHESIS
PLATFORM

ReliaSoft®



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Synthesis Platform Guide
Part Identification: RPSP10

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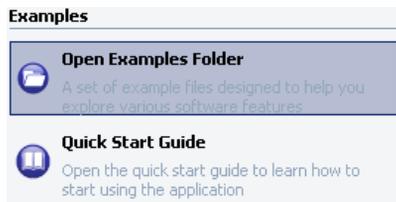
The Synthesis Platform Guide

1

Thank you for your interest in the Synthesis Platform. This guide demonstrates some of the opportunities for integration between Synthesis applications.

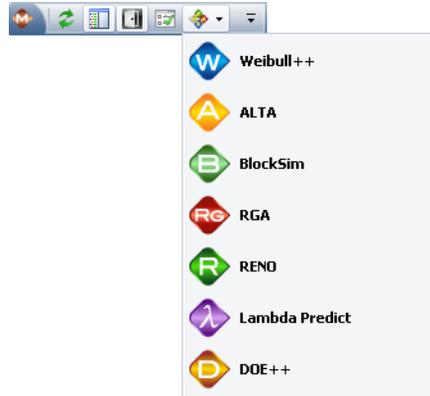
We will ask you to imagine that you are designing and building a new product, then discuss the steps you might take in the various Synthesis applications. Please note that the sample data sets provided are fictional and intended for demonstration purposes. Furthermore, note that this guide shows only some of the many analysis and integration capabilities in the Synthesis Platform. Within each application, you can choose **File > Help** to access a wide array of resources that will help you explore other software capabilities.

This guide is intended to show a possible workflow that is enabled by the integration among the Synthesis applications. For this reason, step-by-step instructions are not provided for most of the tasks; instead, a higher-level discussion is given. The guide will refer to sample projects in the example database that is installed with the software (called “Synthesis10_Guide_Rev1.rsgz10”) to allow you to view the relevant parts of the analysis. To access the file, choose **File > Help** in any Synthesis desktop application, click **Open Examples Folder**, then browse for the file in the **Synthesis** sub-folder.



Tip: To preserve the integrity of the shipped example files, the software creates a copy of the file each time you access a repository in the Examples folder. The copy has the same name as the original file and is saved in the default documents folder for your computer (e.g., My Documents\ReliaSoft\Files). Use the copy to work on the example projects and save your changes. Any changes you make in the copy will not affect the original file.

At various times, you will need to open the sample projects in different Synthesis applications. These transitions are marked in the guide with the application's icon. The simplest way to open the current project in another Synthesis application is to click the **Another Synthesis Application** icon in the Quick Access Toolbar at the top of the window, and choose the application from the list.



Also note that many of the steps in this guide can be performed in Xfmea, RCM++ or RBI. All screenshots for these steps show the RCM++ interface, so if you are working in Xfmea or RBI, your interface may look slightly different from what is shown in the guide.

If you have not purchased licenses for all of the applications used in this guide, you can activate free, expiring demos of the unlicensed applications via the Synthesis installation.

IMPORTANT: Note that it may sometimes be necessary to modify the data in the quick start repository to fit updated instructions or new examples in the latest printing of this quick start guide. This printing of the guide was designed for use with **Synthesis10_Guide_Rev1.rsgz10** (where **_RevX** indicates the database revision). If you try to use a different database revision, the sample projects may not exactly match the instructions printed here. 1) If this guide is older than the latest database revision installed on your computer, you can choose **File > Help > Quick Start Guide** to download the latest printing. 2) If this guide is newer than the latest database revision installed on your computer, you can choose **File > Help > Check for Update** to download the latest software service release.

Sharing Information via Synthesis Resources

2

The Synthesis Platform is intended to facilitate data sharing between different reliability engineering activities, so that the information produced by an analysis performed in one application is available for use in others. As a very simple example, let's say you have a data set from testing Component A. You use Weibull++ to analyze the data set. Then another engineer (let's call her Karen) wants to analyze the reliability and maintainability of a system that incorporates Component A. It makes sense for Karen to use the results from your life data analysis in the reliability block diagram (RBD) that she builds in BlockSim.

BlockSim RBD

System 1

Simulation

DIAGRAM SIMULATION

Simulation Results valid as of 8/9/2013 1:13:31 PM

Distribution fit: Not Fitted

RBD

Number of Blocks: 8

Created: Karen Engineer, 2/20/2014 12:50 PM

Modified: Karen Engineer, 2/20/2014 12:50 PM

Comments

Weibull++ Life Data Analysis

Component A

A39	State F or S	Time to F or S (Hr)	Subset ID 1
1	F	245	
2	F	535	
3	F	793	
4	F	939	
5	F	962	
6	F	1316	
7	F	1371	
8	F	1379	
9	F	1447	
10	F	1451	
11	F	1972	
12	F	1982	
13	S	1999	
14	S	2000	
15	S	2000	
16	S	2000	
17	S	2000	
18	S	2000	
19	S	2000	
20	S	2000	
21			
22			
23			
24			

Main

STANDARD FOLIO

Distribution: 2P-Weibull

Analysis Settings: RRR, SRM, FM, MED

Analysis Summary

Parameters: Beta 1.644765, Eta (Hr) 2257.585661

Other: Rho 0.982623, LK Value -103.777482

Failures/Suspensions: F/S 12/8

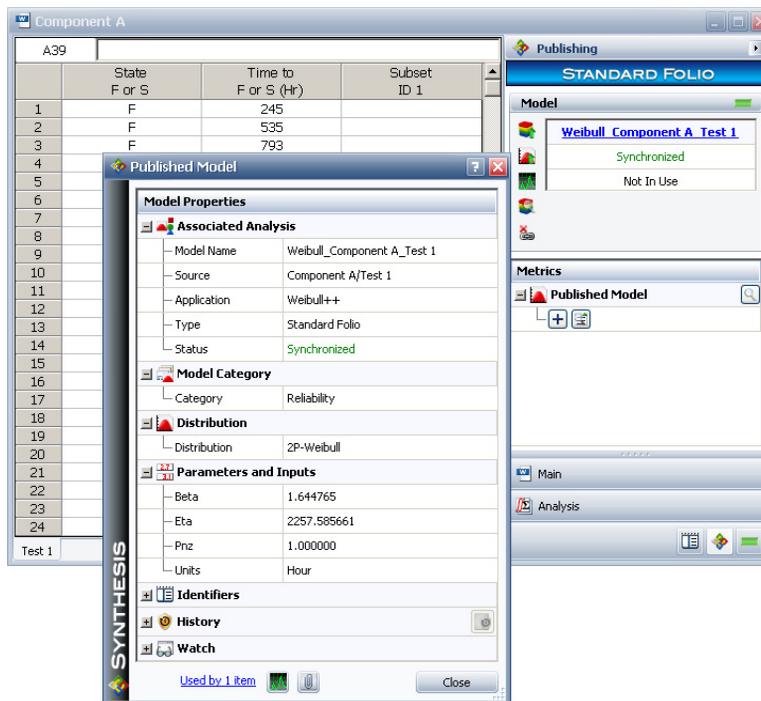
Comments

The Synthesis Platform achieves this sort of integration via a concept pioneered by ReliaSoft, called *object-based reliability modeling* (OBRM). The objects, called *Synthesis resources*, encapsulate information in ways that make it easy to share between Synthesis applications, while shielding the underlying details from view when they're not needed.

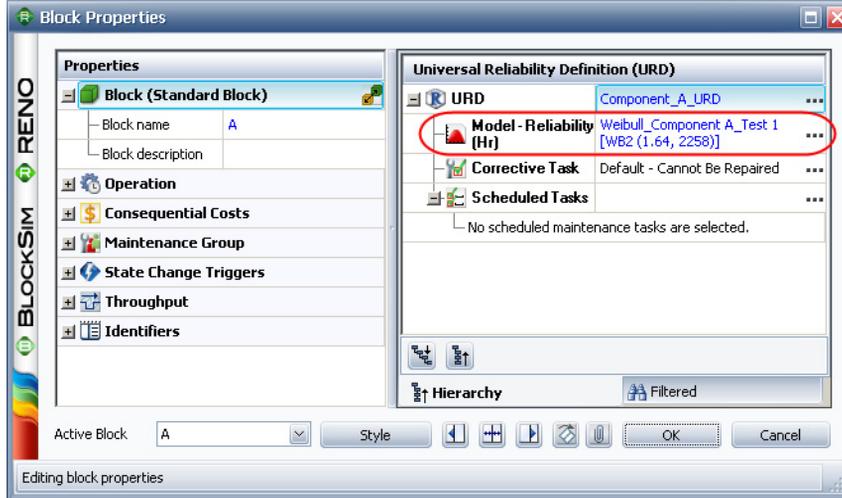
OBRM does not require the recipient to possess a subject matter expertise in the activity that is providing the information. That is, it hides activity-specific complexity and presents the information in a way that can easily be used in other contexts. Going back to our simple example: When Karen needs to use Component A's reliability information in her BlockSim RBD, she doesn't need to see the underlying data set. She just wants to be able to use the results of the Weibull++ analysis to describe the component's reliability.

At the same time, if the underlying data changes, it is important to be able to update the information everywhere that it's used. Let's say you discover an error in your Weibull++ data set. When you reanalyze the data, you need to make sure that the corrected result is used when Karen resimulates the BlockSim RBD.

The Synthesis resource used for the reliability information in our example is called a *model*. Once you have analyzed the data set in Weibull++, you can *publish* the results as a model.



Karen can then associate that model with the block representing Component A in the BlockSim RBD.



When you update and reanalyze the Weibull++ data set, you simply republish the model, and the new results are automatically used the next time Karen simulates the RBD.

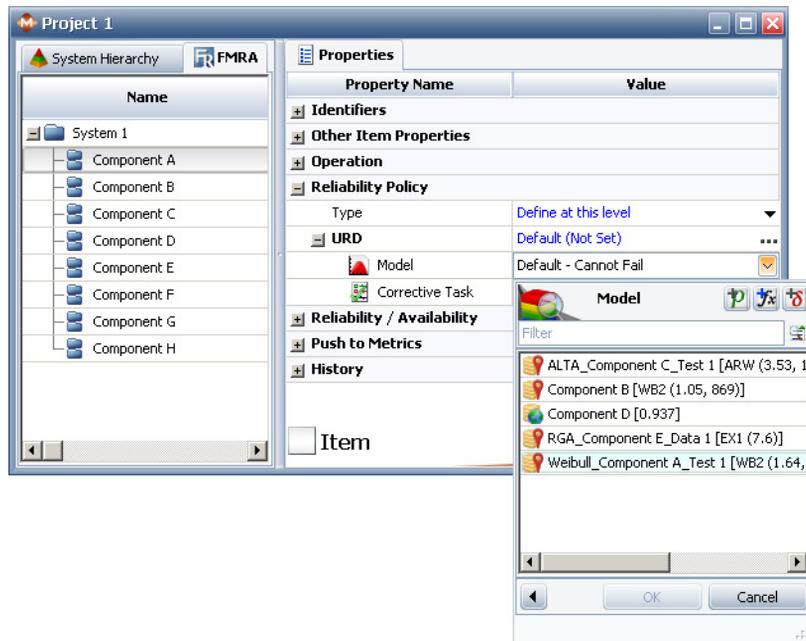
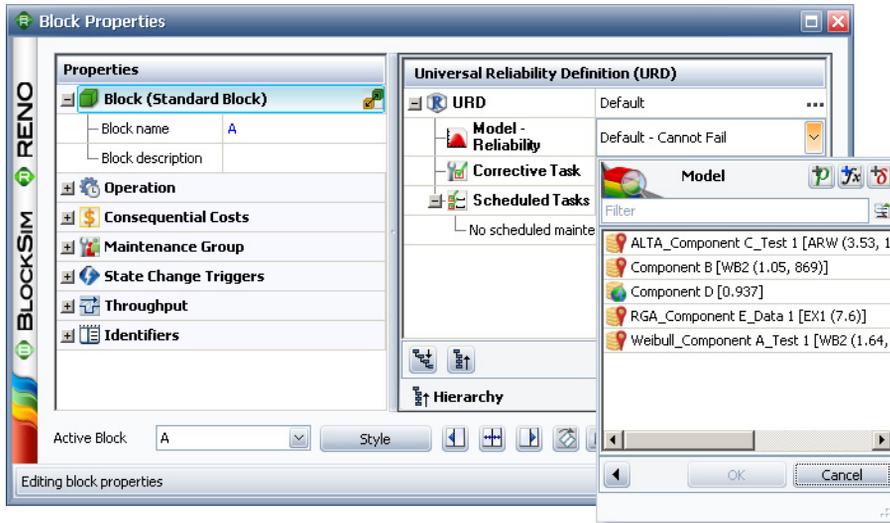
There are several types of Synthesis resources, each used to share a specific kind of information. In this guide, you will encounter the following types:

- **Universal reliability definitions (URDs)** are used to gather together all of the reliability and maintenance characteristics for a particular component or assembly. This can include reliability models as well as corrective and/or scheduled maintenance tasks.
- **Models** can represent probabilities, durations or costs. Any of these values can be either fixed (constant) or time-dependent. Models are used in a variety of ways — to represent an item’s reliability, the duration of a task, the costs associated with a crew, etc. They can be created manually or published from analyses in a variety of Synthesis applications.
- **Tasks** represent maintenance activities. There are two basic kinds of tasks: Corrective tasks are unplanned maintenance activities that are performed when a failure occurs and is discovered. Scheduled tasks include preventive maintenance activities, inspections and on condition maintenance activities.
 - **Crews** represent the labor personnel who will perform the maintenance activity, including the availability of the personnel and the time and costs associated with the labor.
 - **Spare part pools** are used to describe the conditions that determine whether a spare part will be available when needed for a particular maintenance activity, and to specify the time and costs associated with obtaining the spare part.

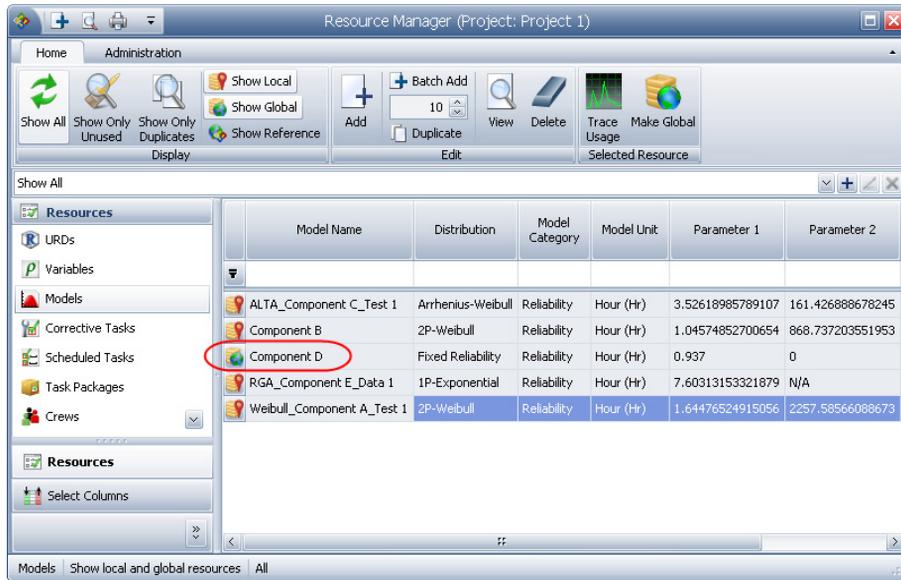
Each application provides the tools you need to create or use Synthesis resources when applicable. For example, you can quickly and easily publish a model from an analyzed data set using the Publishing page in a Weibull++, ALTA or RGA folio's control panel.



Likewise, the Block Properties window in BlockSim and the Reliability Policy node in Xfmea/RCM++/RBI make it easy to select existing URDs/models or create them on the fly.



In addition, all of these applications provide access to the Resource Manager (**Project > Synthesis > Resource Manager**), where you can view and manage all of the resources available for the current project in the current application.



By default, resources are available for use in all analyses in the project (e.g., a model published from an analysis in ALTA can be applied to an FMEA cause in Xfmea, an event in a BlockSim fault tree, and so on). You also have the option to make some resources “global” so they are available for use in different projects throughout the entire database, as shown for the Component D model in the image above. Notice the icon to the left of the model’s name, indicating that it is a global resource.

Using the Synthesis Platform

3

The best way to illustrate how the Synthesis applications can be used together is by looking at an example. This specific example is based on a Design for Reliability (DFR) approach.

You are forming a new company, Chandeliers-R-Us. For your first product, you are designing and building a single-light pendant chandelier. You intend to sell this chandelier for use in residential settings in the United States.

Because this is a new product and the first development project within the organization, neither knowledge nor data yet exist regarding the reliability of the proposed product or any of its components.

The following sections describe some of the reliability activities that your team will perform during product development, and they demonstrate how the Synthesis Platform facilitates and coordinates these activities.

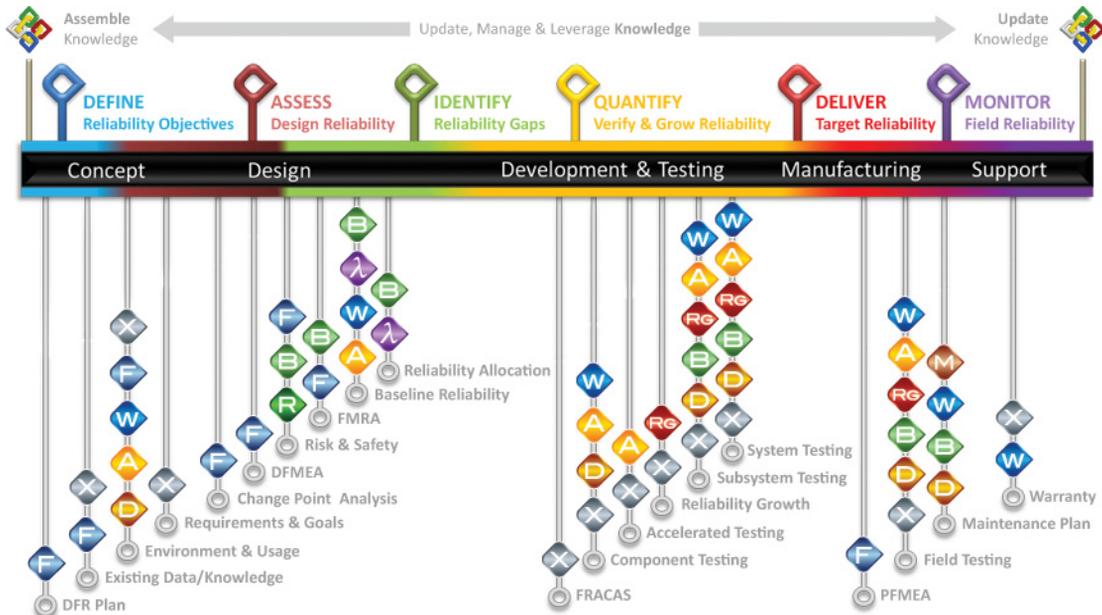


3.1 Create the Project Plan



In this section, you will work with the “1. Chandelier - Preliminary Work” project in the quick start repository, using Xfmea, RCM++ or RBI.

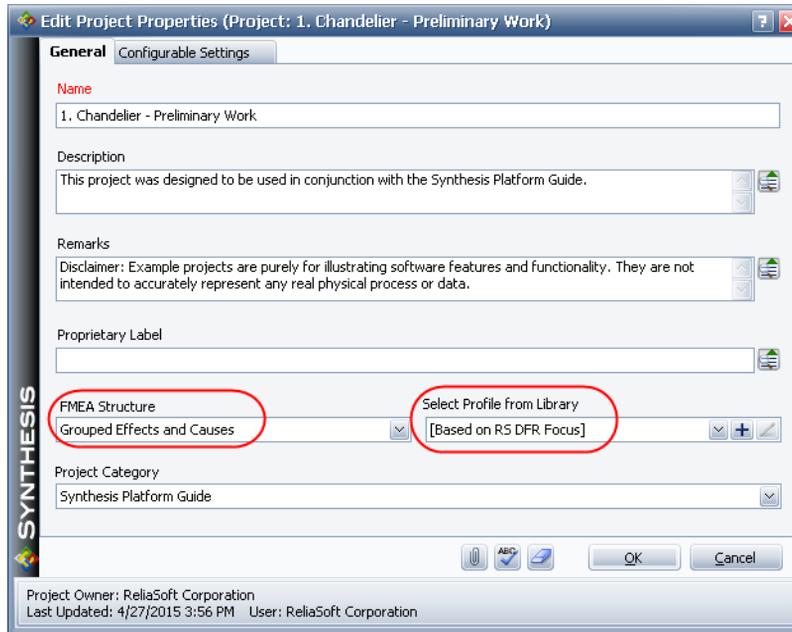
The DFR process involves a series of logical stages that take you from the concept phase through design, development and testing, manufacturing and support.



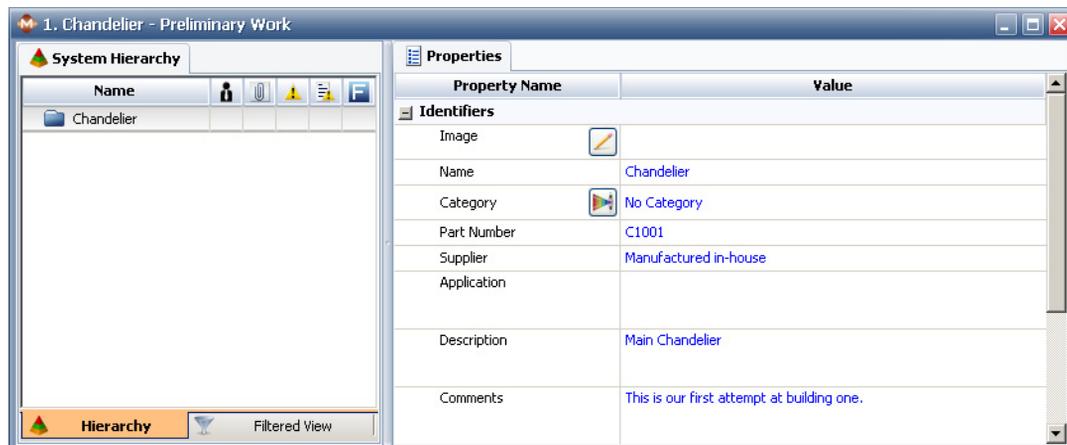
Your first task is to create a new project in a Synthesis repository to store all of the information and analyses that your team will compile/perform for the new single-light pendant chandelier.

You create the project in Xfmea/RCM++/RBI and set the project properties. (To view the properties for the sample project that has already been created, choose **Project > Management > Edit Project Properties**.) For the **FMEA Structure**, you choose **Grouped Effects and Causes**. With this setting, all cause and effect records in the FMEAs will be displayed at the same level of the hierarchy under the failure mode that they are both associated with. For the configurable settings (e.g., the questions that will

be used for risk discovery analysis, the rating scales used to calculate Risk Priority Numbers, etc.), you use the predefined **RS DFR Focus** profile that is installed with the software.



The next task is to create the first item in the System Hierarchy and start defining its characteristics in the Properties tab of the Analysis panel, as shown next.



Then you add a project plan for this item. The Project Planner allows you to define gates and sub-gates to track and manage the steps in your process plan. It also allows you to incorporate actions (either from the

FMEA or defined separately) that are assigned to specific individuals. This allows you to monitor the progress of all reliability activities as they relate to the project. You can create a plan from scratch or use one of the templates as a starting point, and can update the plan using any Synthesis desktop application except MPC. This particular project follows a DFR process, so you will base the plan on the “Project Planner Template2 - Basic Plan” template, which you can import from the Project_Planner_Templates_Rev1.rsr10 example file that is shipped with the software. You then adapt the plan to fit your team's specific needs for this project.

To see how your team's plan for the chandelier looks after the first few gates have been completed, open the Project Planner (**Project > Management > Project Planner**) in the sample project. You will notice that certain properties of higher-level gates (e.g., the status and due date) are determined by the properties of their dependent gates and/or actions. For example, the “Define Reliability Objectives” gate was automatically marked as complete when both of its dependents were completed. In this way, the tool monitors how the progress of individual activities relates to the completion of the entire process.

Note: To ensure that you will be able to see some of the “status” functionality that is built into the software, this example uses a date that is far in the future. By using a future date, the statuses for incomplete gates/actions show as “Not Started” (rather than “Overdue”), which is more likely to appear in a new plan.

Name	Status	Status Label	Planned Start Date	Actual Start Date	Planned Completion Date	Actual Completion Date
1. Chandelier - Preliminary Work	In Progress	In Progress	3/18/2022	3/18/2022	3/4/2023	
Create the DFR Plan	Completed - Late	Completed - Late	3/18/2022	3/18/2022	3/19/2022	3/19/2022
Gather Existing/Data Knowledge	Completed - On Time	Completed - On Time	3/19/2022	3/19/2022	3/21/2022	3/21/2022
Define Reliability Objectives	Completed - On Time	Completed - On Time	3/21/2022	3/21/2022	4/5/2022	3/24/2022
Environment & Usage	Completed - On Time	Completed - On Time	3/21/2022	3/21/2022	3/23/2022	3/21/2022
Requirements & Goals	Completed - On Time	Completed - On Time	3/23/2022	3/23/2022	4/2/2022	3/24/2022
Target Estimation	Completed - On Time	Completed - On Time	3/23/2022	3/23/2022	3/24/2022	3/24/2022
Assess Design Reliability	In Progress	In Progress	4/5/2022	4/5/2022	4/23/2022	
Change Point/Risk Discovery	In Progress	In Progress	4/5/2022	4/5/2022	4/6/2022	
DFMEA	In Progress	In Progress	4/6/2022	4/6/2022	4/10/2022	
Risk & Safety Analysis	In Progress	In Progress	4/10/2022	4/10/2022	4/12/2022	
FMRA	In Progress	In Progress	4/12/2022	4/12/2022	4/18/2022	
Create FMRA	In Progress	In Progress	4/12/2022	4/12/2022	4/13/2022	
Vet FMRA	In Progress	In Progress	4/13/2022	4/13/2022	4/18/2022	
Compute Baseline Reliability	In Progress	In Progress	4/18/2022	4/18/2022	4/23/2022	
Identify Reliability Gaps	In Progress	In Progress	4/23/2022	4/23/2022	4/26/2022	
Reliability Allocation	In Progress	In Progress	4/23/2022	4/23/2022	4/26/2022	
Development	In Progress	In Progress	4/26/2022	4/26/2022	7/27/2022	
Manufacture & Deploy	In Progress	In Progress	7/27/2022	7/27/2022	11/4/2022	
Monitor Field Returns	In Progress	In Progress	11/4/2022	11/4/2022	3/4/2023	

3.2 Gather Existing Data/Knowledge

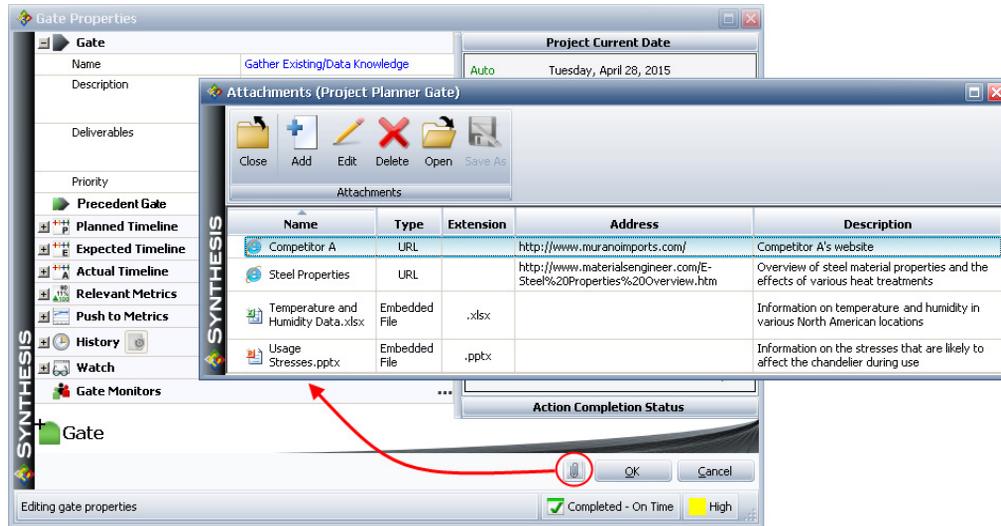


In this section, you will continue working with the “1. Chandelier - Preliminary Work” project in the quick start repository, using Xfmea/RCM++/RBI.

The next gate in the project plan is to gather (or at least identify) the information that you will need for subsequent activities. This would include information such as use stress conditions, competing products, material properties, etc. If similar designs exist, FRACAS data regarding observed failure modes, occurrence rates, etc. are also invaluable.

You can attach the information that you gather to the project plan, either by linking to web pages or files, or by storing a copy of the file in the database. For the chandelier, your team attaches four items to the

“Gather Existing Data/Knowledge” gate in the planner. They are accessible by clicking the **Attachments** icon in the Gate Properties window, as shown next.



3.3 Identify the Use Conditions



In this section, you will continue working with the “1. Chandelier - Preliminary Work” project in the quick start repository, using Xfmea/RCM++/RBI.

Establishing the limits on the environmental and use conditions is one of the most important elements of the DFR process. In the case of the chandelier, this is fairly simple, as the product is intended for use in residential settings in North America. Based on the knowledge gathered for the “Gather Existing Data/Knowledge” gate, you return to the Properties tab for the chandelier and enter the environmental

conditions in the **Application** field, as shown next. This information will be used during the FMEA and test design.

Property Name	Value
Identifiers	
Image	
Name	Chandelier
Category	No Category
Part Number	C1001
Supplier	Manufactured in-house
Application	Residential use. Stable temperature. Humidity range of 25% to 95%. Voltage fluctuations from 121 V to 129 V.
Description	Main Chandelier
Comments	This is our first attempt at building one.
Keywords	
Other Item Properties	
History	

3.4 Set Reliability Requirements



In this section, you will continue working with the “1. Chandelier - Preliminary Work” project in the quick start repository. Some of the steps are performed in Weibull++ and some in Xfmea/RCM++/RBI.

Your next step is to set high-level reliability requirements. Depending on the industry and application, these could be driven by any of a number of factors, such as OEM specifications, marketing/customer needs, benchmarking specifications, best practices, costs, safety/regulatory concerns, contract requirements, etc.

For the chandelier, the team decides to use a cost-based approach.

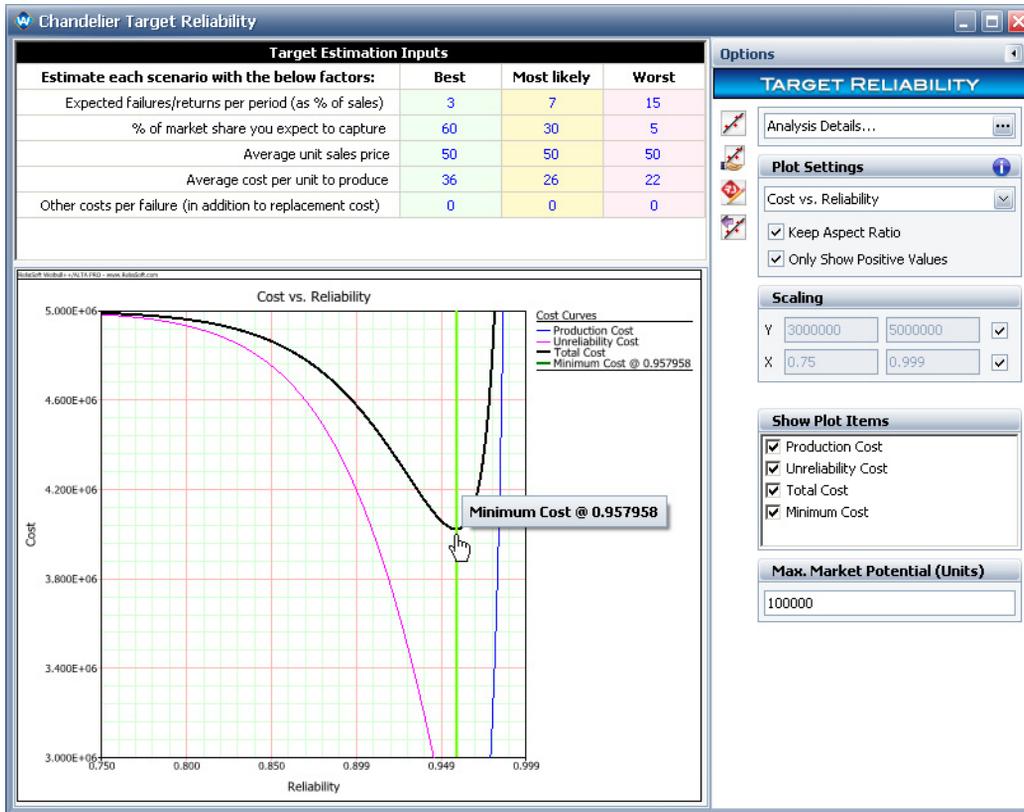
W WEIBULL++

You open the Synthesis Launcher from the Quick Access Toolbar to open the same project in Weibull++. (This feature can also be accessed by choosing **File > Launch Application** or **Home > Launch > Another Synthesis Application**.)



Then you open the Target Reliability tool and use the settings shown next (“*Chandelier Target Reliability*” in the sample project). The table at the top of the window contains the team’s inputs for the best, worst and most likely scenarios, while the plot shows the Cost vs. Reliability curves calculated based on those inputs.

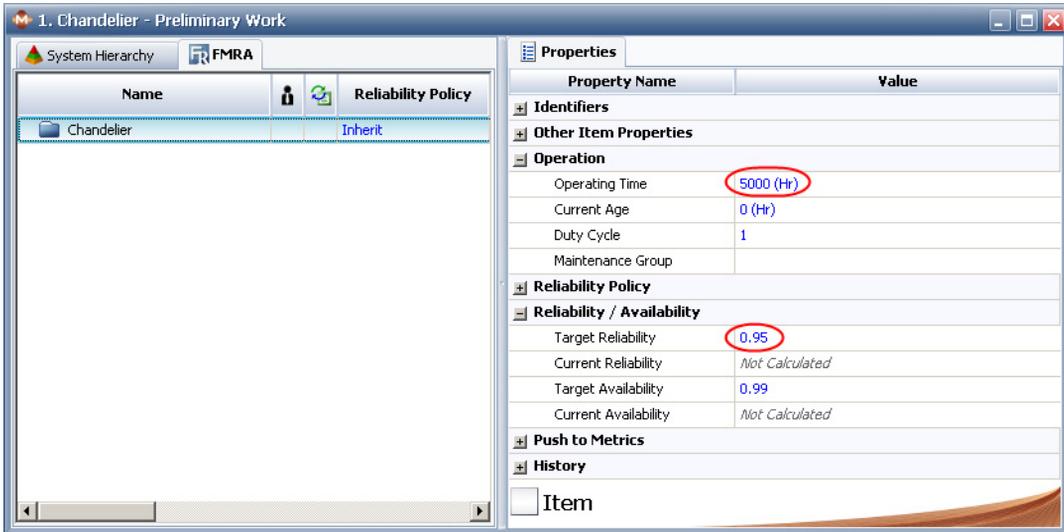
Pointing to the Minimum Cost line in the plot, you see that the minimum cost is reached at a reliability of 95.7958%.



Based on this, the team decides on a target reliability of 95% for 5,000 hours of operation.



You return to Xfmea/RCM++/RBI by clicking its icon in the Windows taskbar. If the FMRA tab is not already visible in the System panel, choose **View > Show > Show FMRA**. You then enter these values on the Properties tab, as shown next. For other fields, default settings are kept.

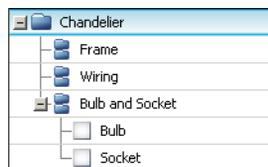


3.5 Risk Discovery



In this section, you will switch to the “2. Chandelier - Assess Design Reliability” project in the quick start repository, while still using Xfmea/RCM++/RBI.

With the target reliability specified, you can now take a closer look at the system. The basic design of the chandelier consists of the Frame, Wiring, and Bulb and Socket assemblies. In Xfmea/RCM++/RBI, you add assemblies and components to the system hierarchy, as shown next.



At this point, you begin to consider the issue of risk for the system. The purpose of this is to identify the critical items to focus on; you should perform FMEAs for these items.

For situations in which a prior design exists, the team might perform a *change point analysis* to assess what has changed in the new version. For items that have no changes and have performed satisfactorily in the prior design, further analysis may not be warranted. However, changes that can affect reliability may constitute a risk that requires further attention, such as:

- Change in the design.
- Change in the manufacturer.
- Change in the supplier, supplier design or process.
- Change in the usage environment.
- Change in the system - interface points.
- Change in the system - upstream and downstream parts.
- Change in the specification.
- Change in the performance requirements.
- Any other changes that can affect reliability.

Likewise, a similar set of assessment criteria can be applied to evaluate the risk in a new design.

Your team uses the configurable Risk Discovery feature in Xfmea/RCM++/RBI to perform separate analyses for four items in the system hierarchy: Frame, Wiring, Bulb and Socket. The specific questions used in this project are based on the “RS DFR Focus” profile that is installed with the software; they are suitable to consider either changes from a prior design or potential concerns with a new design (as is the case for this chandelier).

The following picture shows the analysis for the Frame. To view all four analyses in the sample project, simply select each item and then view the Risk Discovery tab in the Analysis panel.

Label	Question	Response
New Technology	Does the design involve new technology?	No
New Application	Does the design apply existing technology in a new way?	No
Historical Problems	Have there been historical problems with this item?	No
Safety Issues	Is there a potential for safety-related issues?	Yes
Mission-Critical	Is this a mission-critical item?	Yes
Regulatory	Changes or concerns related to Regulatory Requirements?	No
Specifications	Changes or concerns related to the Specifications?	No
Functions	Changes or concerns related to the expected Functions?	No
Performance	Changes or concerns related to the Performance and/or Performance Requirements?	No
Loading	Changes or concerns related to the expected Loading?	No
Environmental Loads	Changes or concerns related to other Environmental Loads?	No
Use Loads/Stresses	Changes or concerns related to Use Loads/Stresses?	No
Max Temp.	Changes or concerns related to the High Temperature Limit?	No
Use Temp.	Changes or concerns related to the expected Use Temperature?	No

Mark item for more detailed analysis

Based on the results of these analyses, the team decides to perform Design FMEAs (DFMEAs) for all four items.

3.6 Design FMEAs



In this section, you will continue working with the “2. Chandelier - Assess Design Reliability” project in the quick start repository, using Xfmea/RCM++/RBI.

You use Xfmea/RCM++/RBI to record the DFMEAs for the Frame, Wiring, Bulb and Socket. Each DFMEA can be done by the same or different teams. A Risk Priority Number (RPN) approach is used to assist in prioritizing the causes that need mitigation.

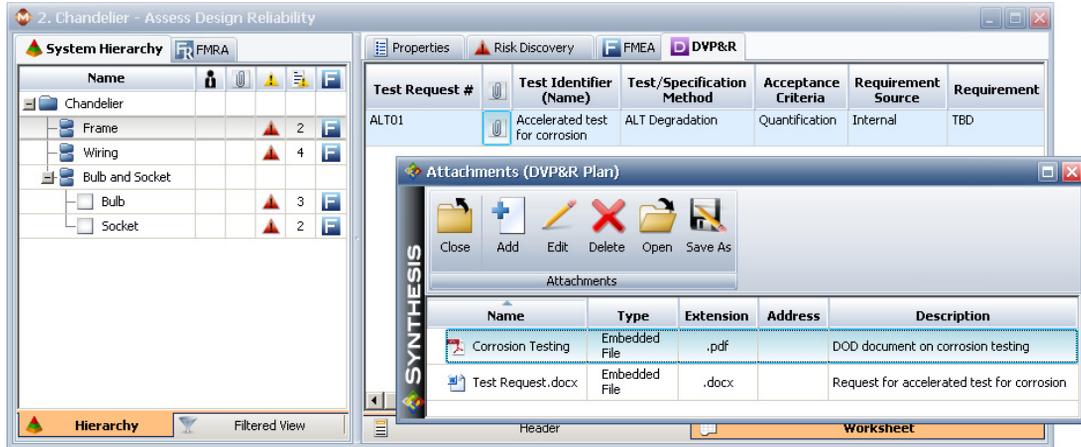
For example, the following picture shows the FMEA for the Frame. (To see this analysis in the sample project, select the Frame in the system hierarchy and then view the FMEA tab in the Analysis panel.)

Description	RPN	RPNr
Hold the Chandelier together		
Frame Cracks, Falls		
Grouped Effects		
Break up of Chandelier (9) Possible injury (10)		
Causes		
Corrosion	300	300
Controls		
Actions		
Perform an accelerated test to better understand corrosion.		
Reliability Policy - Based on Initial Occurrence		
Occurrence: (6 - 1 in 100) [EX1 (99499)]		
Tasks		
Metal fatigue due to swinging, cyclical stresses	60	60

For this item, the corrosion failure mode is the biggest concern. Its probability of occurrence, while just an estimate at this time, is worrisome. The team has determined that additional information is needed to better understand this failure mechanism (e.g., from literature searches on corrosion, expert opinion and/or testing). Therefore, the requirement to perform an accelerated test is recorded as an action in the FMEA.

Note: Within Xfmea/RCM++/RBI, different views of the FMEA are available, from a traditional spreadsheet-style view to a more efficient, flexible and advanced hierarchical view. This guide uses the hierarchical view, which provides the most flexibility.

You also transfer this action to a Design Verification Plan (DVP&R) and attach some related documents, as shown next. (To see this analysis in the sample project, select the Frame in the system hierarchy and view the DVP&R tab in the Analysis panel.)



In a similar manner, the FMEAs for the Wiring, Bulb and Socket identify other issues of concern and additional tests that may help to improve the chandelier's reliability. (To view these analyses in the sample project, click each item in the system hierarchy and view the FMEA tab in the Analysis panel.)

When the FMEAs are completed, you add any relevant actions to the project plan. For example, the following picture shows the “Development” stage of the plan updated with frame corrosion and bulb test plans that were recommended by the FMEA team.

Development		In Progress	4/26/2022	4/26/2022	7/27/2022	
Set Up FRACAS		In Progress	4/26/2022	4/26/2022	4/28/2022	
Component Testing		In Progress	4/28/2022	4/28/2022	7/27/2022	
ALT for Corrosion		In Progress	4/28/2022	4/28/2022	5/26/2022	
Bulb Testing		In Progress	4/28/2022	4/28/2022	7/27/2022	
Reliability Growth Monitoring		In Progress	4/28/2022	4/28/2022	7/27/2022	
Subsystem Testing		In Progress	5/28/2022	5/28/2022	6/27/2022	
System Testing		In Progress	6/7/2022	6/7/2022	7/7/2022	

We will discuss some of the specific test results later in this document (Section 3.12 on page 47).

3.7 Failure Modes and Reliability Analysis (FMRA)



In this section, you will continue working with the “2. Chandelier - Assess Design Reliability” project in the quick start repository, using Xfmea/RCM++/RBI.

Traditionally, DFMEA analysis focuses on qualitative inputs to assess and rank the risk associated with specific failure modes and their eventual mitigation, through an RPN approach or other ranking criteria. We may, however, wish to also use the FMEA as a starting point for certain quantitative analyses.

ReliaSoft's powerful Failure Modes and Reliability Analysis (FMRA) view offers a representation of the system hierarchy that shows the FMEA functions, failures and causes for each item directly within the hierarchy.

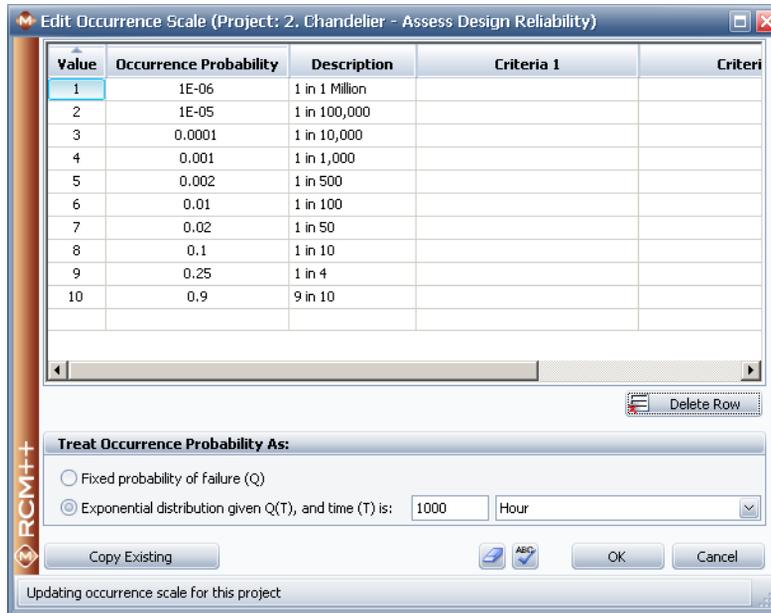
This view allows you to assign reliability characteristics at the item level or at the function, failure or cause levels. This can be used for a variety of purposes, including the fault tree analysis that will be discussed in Section 3.8, the simulation-based risk assessment discussed in Section 3.9 and the baseline reliability estimation discussed in Section 3.10.

To proceed with any of these analyses, we first need to quantify the failure or event probabilities for each cause in each FMEA.

If prior data exist or time is available for testing, it is a simple matter to determine these probabilities. However, for the single-light pendant chandelier, no data are available at this point other than the qualitative inputs provided during the FMEA analysis in the form of the occurrence rating scale that was used for RPN calculation. We can use this information as a starting point because, even though qualitative, the scales used in any FMEA should have some quantitative equivalent (e.g., “Unlikely” is 1 in a million). The conversion of these inputs into either fixed numerical probabilities or simple lifetime distributions (e.g., exponential) provides a quantitative starting point.

In this case, you know that the FMEA teams assigned occurrence ratings based on the probability that the failure would occur by 1,000 hours of operation. Therefore, it is possible to use a time-dependent exponential distribution instead of a fixed probability. This will allow the software to calculate the probability of failure for any operating time specified for the analysis (which is 5,000 hours in this case).

In Xfmea/RCM++/RBI, you configure the occurrence rating scale that has been defined for the current project as shown in the following picture. (To access this window, choose **Project > Management > Configurable Settings > Occurrence**.)



With these settings, a 1-parameter exponential model will be built for each occurrence rating using the probability of failure entered in the **Quantitative Value** field (Q) and the time specified for T (1,000 hours), as follows:

$$\text{Probability of Failure at Time } T = Q(T)$$

Assuming an exponential distribution, its single parameter λ can be estimated as follows:

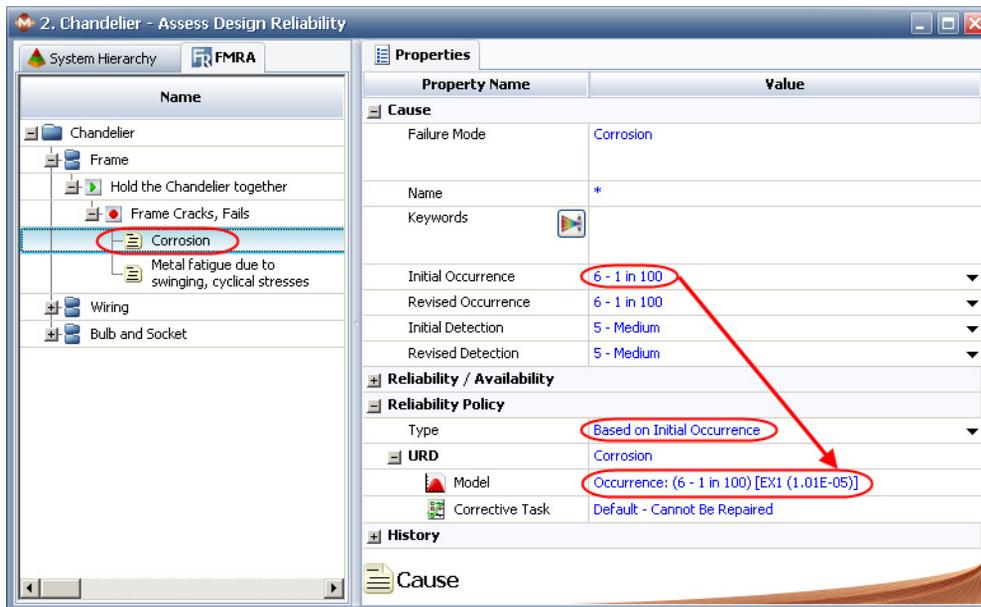
$$1 - Q(T) = R(t) = e^{-\lambda t}$$

$$\frac{-\ln(1 - Q(t))}{t} = \lambda$$

It is common knowledge that the exponential distribution, with its assumption of a constant failure rate, is flawed for anything that exhibits any type of degradation (i.e., gets worse with age). However, for the purposes of a first cut estimate it is still useful. If the analyst feels that a more realistic model is needed, the occurrence probability can subsequently be easily modified to use any other distribution. The model

can also be linked to source data, as demonstrated later in this guide. In the absence of data, you could also use the model wizard to more realistically describe the occurrence probability. For now, however, you decide to start with the exponential assumption.

Initially, you simply want to use the FMRA to assign reliability models to each cause in order to proceed with more complex risk analysis. To do this in the FMRA, you modify the reliability policy for each cause so that it is calculated based on the probabilistic model that corresponds to the initial occurrence rating. (These models are not resources that can be used elsewhere; they are simply representations of probability using an exponential distribution.) As an example, the following picture shows the FMRA properties for the Corrosion cause in the Frame FMEA.



3.8 Fault Tree Analysis



In this section, you will continue working with the “2. Chandelier - Assess Design Reliability” project in the quick start repository, using BlockSim.

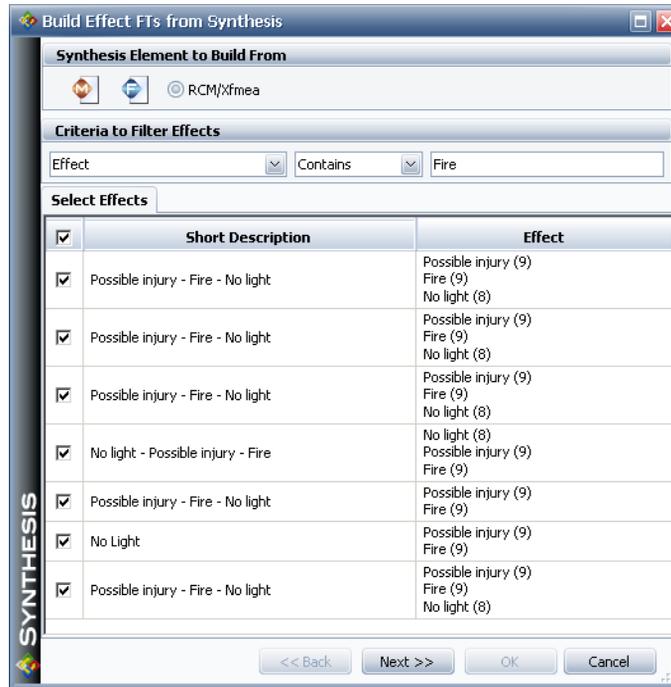
You can now open the project in BlocksIm, where you can quantify the chandelier’s overall risk of fire based on different causes in the FMEAs.

In the chandelier, fire is a possible effect across various assemblies. The table below shows the portions of all of the FMEAs that lead to fire.

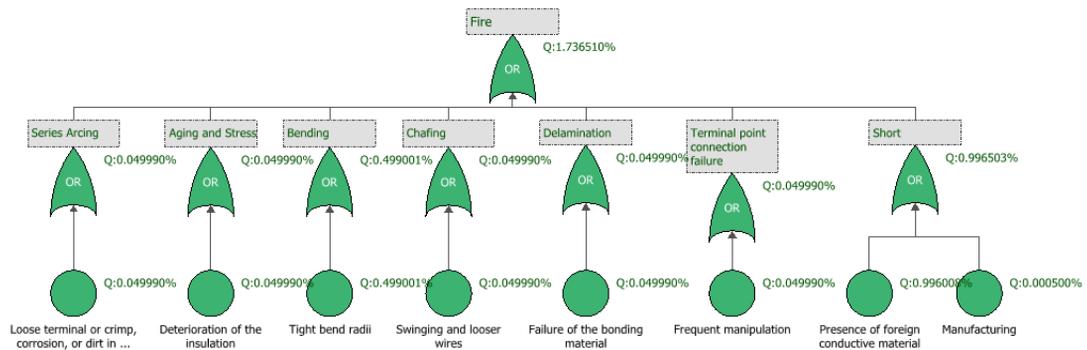
System	Assembly	Function	Failure	Effect(s)
Chandelier	Frame	Hold the chandelier together	Frame cracks	No light; Break up of chandelier; Possible injury
	Wiring	Provide electricity	Aging and stress	Possible injury; Fire; No light
			Bending	Possible injury; Fire; No light
			Chafing	Possible injury; Fire; No light
			Delamination	Possible injury; Fire; No light
			Terminal point connection failure	Possible injury; Fire; No light
			Series arcing	Possible injury; Fire; No light
	Bulb	Provide light	Filament burns	No light
			Bulb shatters	Possible injury; No light
			Base fails to make contact	No light
			Insufficient light	Customer dissatisfaction
	Socket	Provide electricity to bulb	Fails to make contact	No light
			Short	Possible injury; Fire; No light

To combine all of this information together, BlockSim provides a convenient utility that queries the FMEAs that you performed in Xfmea/RCM++/RBI and automatically generates fault trees that show all of the possible failure modes that could result in a particular outcome. For example, the following picture shows the query that generates a fault tree for any failure effect that contains the word “fire.” (To access

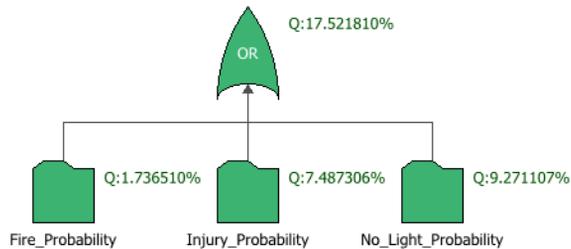
this utility in BlockSim, choose **Insert > Build from Synthesis > Build Effect FTs from Synthesis.**) This step has already been performed in the sample project.



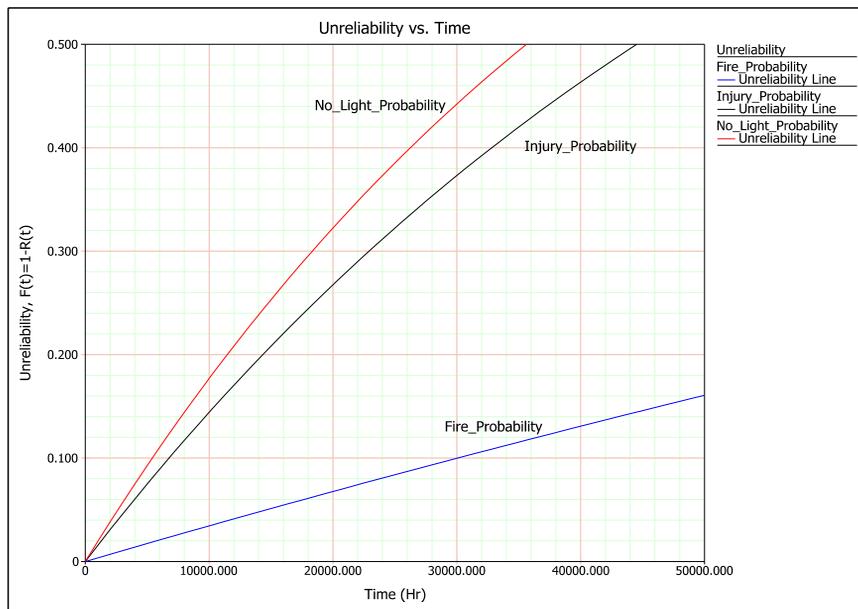
The resulting fault tree (“*Fire_Probability*” in the sample project) shows all of the possible failure modes that could result in fire and calculates the overall probability that fire may occur by 5,000 hours, as shown next.



It is a simple matter to do the same for the “possible injury” and “no light” effects. You then use these fault trees as subdiagrams in a fault tree (“*Any_Effect*” in the sample project) that shows the probability that any of these effects will happen by 5,000 hours, as shown next.

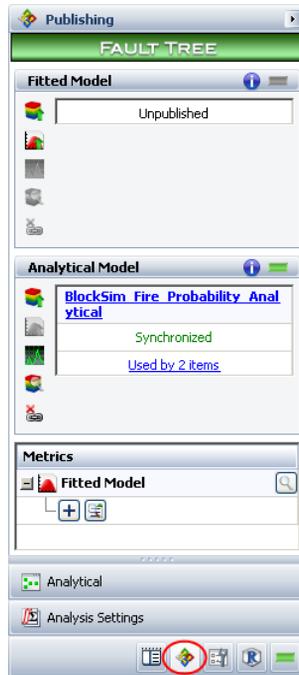


You also create an overlay plot (“*Effect Probabilities of Occurrence*” in the sample project) that shows how the probabilities of occurrence of the effects compare, as shown next. (Note that labels have been added here for clarity.)



Finally, you return to the fire probability fault tree and publish it as a model that can be used in other analyses. The following picture shows the Publishing page of the fault tree's control panel, which provides

the tools you need to create and manage published models based on a particular BlockSim diagram. (To view this page, click the **Publishing** icon at the bottom of the control panel, as indicated in the picture.)



3.9 Using Flowchart Simulation and DOE



In this section, you will continue working with the “2. Chandelier - Assess Design Reliability” project in the quick start repository. Some of the steps are performed in RENO and some in DOE++.

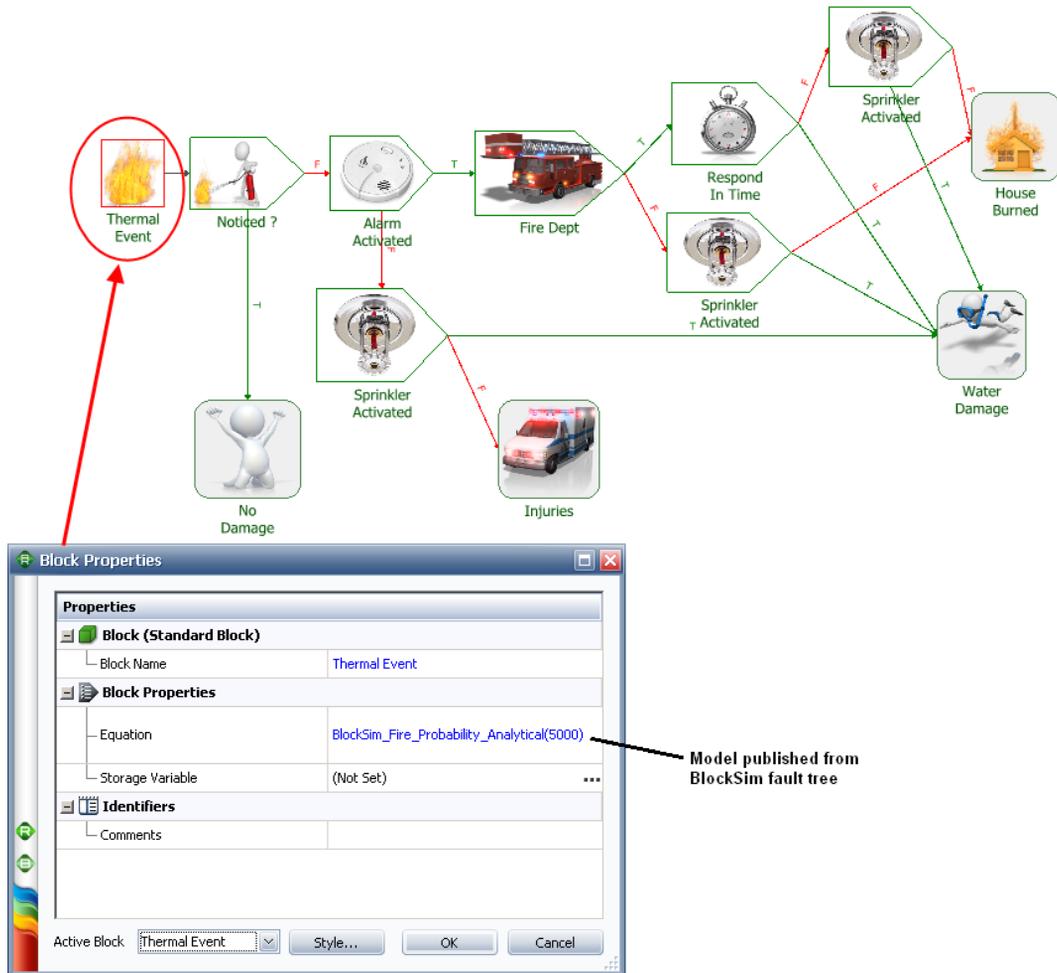
The information about risk that you have obtained thus far can be put to further use. For example, the probability model that you created for the “fire” effect can now be used to help you understand the potential outcomes associated with fire and thereby assess and quantify the associated risk for the end user.

To evaluate the potential outcomes associated with fire, you build a RENO flowchart that starts with the probability of fire, based on the published model at 5,000 hours, and takes into account the following event probabilities:

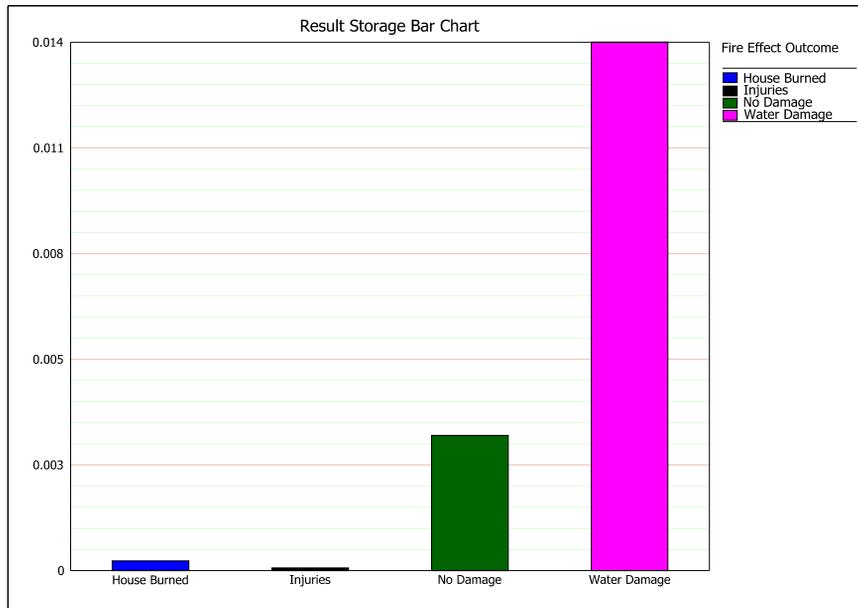
- The probability of the fire being noticed right away = 0.2.
- If the fire goes unnoticed, the probability of the alarm being activated = 0.95.

- If the alarm is activated, the probability of the fire department receiving the notification = 0.9.
- The probability of the fire department arriving in time = 0.9.
- The sprinkler system may be activated if the alarm fails or if the fire department fails to respond in time. The probability of the sprinkler system being successfully activated in either case = 0.9.

The following picture shows the flowchart (“*Fire Effect Outcome*” in the sample project), along with the properties of the originating event (i.e., fire).



Simulating this flowchart and plotting the results gives you an idea of the probabilities of various outcomes.



In this case, the outcome of greatest concern to you is the possibility of injury. You decide to use Design of Experiments (DOE) analysis to determine the factors (or events) that have the greatest effect on the probability of injury due to fire.

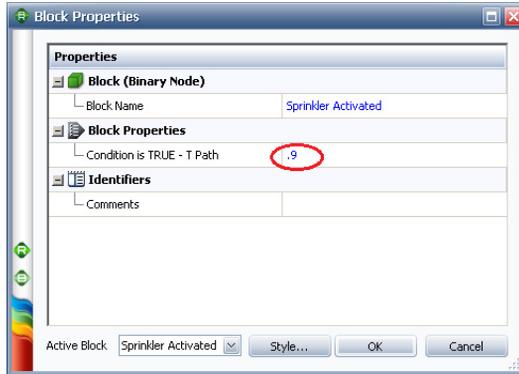
To do this, you first duplicate the RENO flowchart. In the new flowchart ("*Fire Effect Outcome DOE*" in the sample project), you replace the following probability values with variables.

- Noticed
- Alarm Activated
- Respond in Time
- Sprinkler Activated

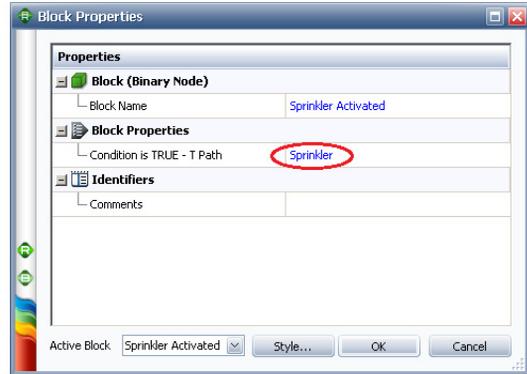
A *variable* is a Synthesis resource that stores a numerical value and allows you to assign a name to that value. You can then use the variable name in place of the actual value in the equations that you create, and the value of the variable can be changed during simulation.

For example, in the Block Properties windows shown next, the one on the left shows the probability of sprinkler activation defined as a constant (0.9) in the original flowchart, while the one on the right shows

it defined using a variable called “Sprinkler” in the new flowchart. The variable method allows you to try different values during simulation.



Using Fixed Probability Value



Using Variable for Probability

In the new flowchart, you also set the Injuries block (i.e., the resulting probability of injury) to store its value in a variable. Storing the result in this way will allow it to be used in a simulation worksheet, as explained in the following steps.

DOE++

You then open the project in DOE++ and build a general full factorial design (“*Injury from Fire*” in the *sample project*) that sets eight different levels to be considered for each of the factors, as shown next. (To access this design summary in the sample project, click the **Detailed Summary** link on the Design tab of the design folio.)

General Full Factorial

Response Properties	
Name	Units
Injury Probability	

Factor Properties												
Abbreviation	Name	Units	Type	Number of Levels	Level 1 (Low)	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8 (High)
NT	Noticed		Quantitative	8	0.05	0.1	0.2	0.3	0.4	0.5	0.7	0.8
AL	Alarm Activated		Quantitative	8	0.1	0.2	0.3	0.5	0.7	0.9	0.95	0.99
SP	Sprinkler Activated		Quantitative	8	0.2	0.3	0.5	0.7	0.8	0.9	0.95	0.99
FD	FD Respond in Time		Quantitative	8	0.1	0.3	0.5	0.7	0.8	0.9	0.95	0.99

Additional Settings	
# of Unique Runs	4096
# of Blocks	1
Center Points / Block	0
# of Replicates	1
Block on Replicates	No
Total # of Runs	4096

You then transfer the factor settings to a new simulation worksheet (“*Simulation Worksheet1*” in the *sample project*). In this case, you will access the same worksheet in both DOE++ and RENO in order to a)

design an experiment in DOE++, b) use a RENO flowchart to obtain the “response” data via simulation, and then c) return to DOE++ and analyze the simulated response data.

The following picture shows how the worksheet looks after you have transferred the factor settings from the experiment design, but before the response data has been populated by RENO. (You won't be able to see this stage of the analysis in the sample project. The simulation worksheet in the sample project is complete, and looks like the step shown on page 35.)

A4100	Noticed	Alarm Activated	Sprinkler Activated	FD Respond in Time	Injury Probability
1	0.4	0.3	0.3	0.5	
2	0.1	0.7	0.3	0.8	
3	0.1	0.2	0.8	0.1	
4	0.5	0.5	0.2	0.5	
5	0.05	0.9	0.5	0.1	
6	0.1	0.2	0.2	0.5	
7	0.3	0.7	0.9	0.5	
8	0.7	0.99	0.3	0.95	
9	0.8	0.3	0.2	0.8	
10	0.7	0.1	0.99	0.5	
11	0.4	0.95	0.95	0.3	
12	0.7	0.95	0.5	0.3	
13	0.2	0.7	0.8	0.7	
14	0.5	0.5	0.7	0.1	
15	0.3	0.95	0.99	0.1	
16	0.5	0.1	0.8	0.95	
17	0.1	0.95	0.7	0.1	
18	0.2	0.1	0.2	0.99	
19	0.3	0.95	0.7	0.95	
20	0.7	0.1	0.3	0.3	

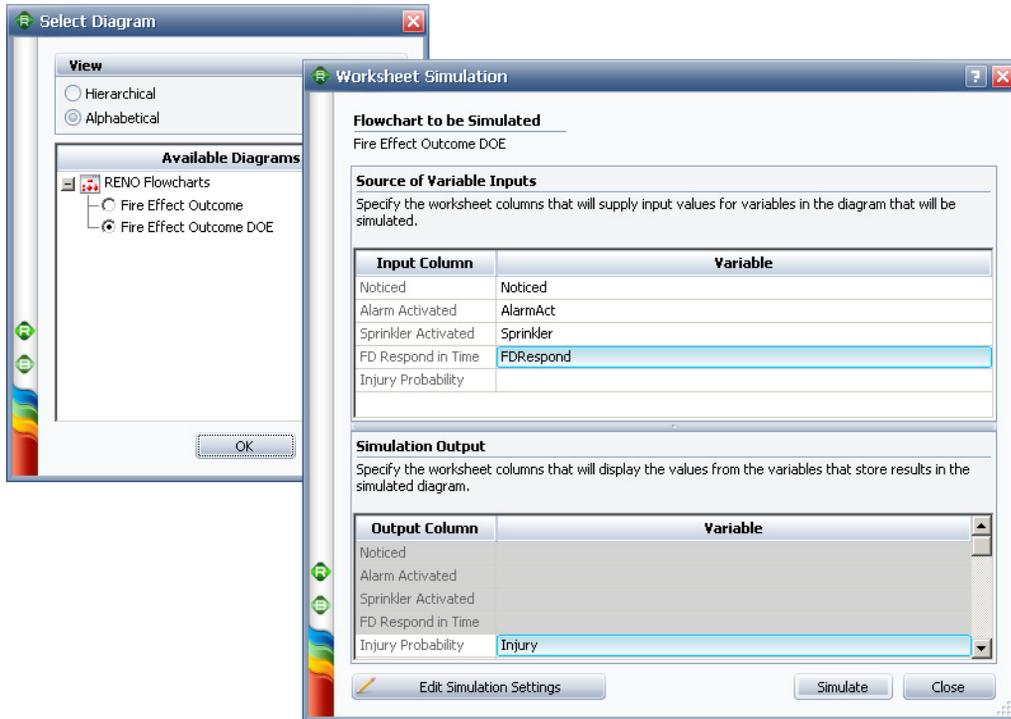
Note: Complete data set is not shown.

You click the **Commit and Lock** button in the control panel to save the changes and lock the worksheet in DOE++ so you'll be able to work with it in RENO.

RENO

You then return to RENO and open the same simulation worksheet. When you click the **Simulate** icon in the control panel, the Select Diagram window appears. In this window, you first select the flowchart diagram that will be used to generate the response data. Then you specify which variables from the

flowchart will be associated with the factors (inputs) and response (output) in the DOE analysis. The following pictures show these settings.



When you run the simulation (using 1,000 simulations with a seed of 1 for repeatability), the factor settings entered by DOE++ into the simulation worksheet are used by each specified variable in the RENO simulation. And likewise, the values generated by the RENO flowchart and stored in the Injury

variable are used to populate the DOE response column in the simulation worksheet. For example, consider the values in the first row of the simulation worksheet, as shown next.

The screenshot shows a 'Simulation Worksheet' window with a table of simulation results. The first row of data is circled in red. The table has columns for 'Noticed', 'Alarm Activated', 'Sprinkler Activated', 'FD Respond in Time', and 'Injury Probability'. The first row contains the values 0.4, 0.3, 0.3, 0.5, and 0.005105338871 respectively. To the right of the table is a 'Settings' panel with 'Commit and Lock' and 'SIMULATION WORKSHEET' buttons. The 'Settings' panel lists 'Input Columns' and 'Output Columns' with their corresponding variable names.

	Noticed	Alarm Activated	Sprinkler Activated	FD Respond in Time	Injury Probability
1	0.4	0.3	0.3	0.5	0.005105338871
2	0.1	0.7	0.3	0.8	0.00328200356
3	0.1	0.2	0.8	0.1	0.002500574141
4	0.5	0.5	0.2	0.5	0.00347301964
5	0.05	0.9	0.5	0.1	0.0008248421645
6	0.1	0.2	0.2	0.5	0.01000229656
7	0.3	0.7	0.9	0.5	0.0003646670622
8	0.7	0.99	0.3	0.95	3.646670622E-005
9	0.8	0.3	0.2	0.8	0.001944890998
10	0.7	0.1	0.99	0.5	4.688576514E-005
11	0.4	0.95	0.95	0.3	2.60476473E-005
12	0.7	0.95	0.5	0.3	0.0001302382365
13	0.2	0.7	0.8	0.7	0.0008335247136
14	0.5	0.5	0.7	0.1	0.001302382365
15	0.3	0.95	0.99	0.1	6.07778437E-006
16	0.5	0.1	0.8	0.95	0.001562858838
17	0.1	0.95	0.7	0.1	0.0002344288257
18	0.2	0.1	0.2	0.99	0.01000229656
19	0.3	0.95	0.7	0.95	0.0001823335311
20	0.7	0.1	0.3	0.95	0.00328200356
21	0.2	0.9	0.7	0.9	0.0004167623568
22	0.8	0.95	0.99	0.3	1.73650982E-006
23	0.5	0.3	0.2	0.7	0.004862227496
24	0.2	0.1	0.95	0.1	0.0006251435352

Settings

Input Columns

Noticed	Noticed
Alarm Activated	AlarmAct
Sprinkler Activated	Sprinkler
FD Respond in Time	FDRespond

Output Columns

Injury Probability	Injury
--------------------	--------

Last Imported From

Injury from Fire
10/23/2013 10:54:13 AM

Last Exported To

Injury from Fire
10/23/2013 11:13:46 AM

[Fire Effect Outcome DOE](#)

In the first simulation, the value in the Noticed column, 0.4, is used by the Noticed variable to define the probability that the fire is noticed. Similarly, the AlarmAct variable is set to 0.3, the Sprinkler variable is set to 0.3 and the FDRespond variable is set to 0.5. Given these values in the flowchart simulation, the probability of injury is found to be approximately 0.005.

After the response data has been generated, you again commit and lock the simulation worksheet so you'll be able to work with it in DOE++.

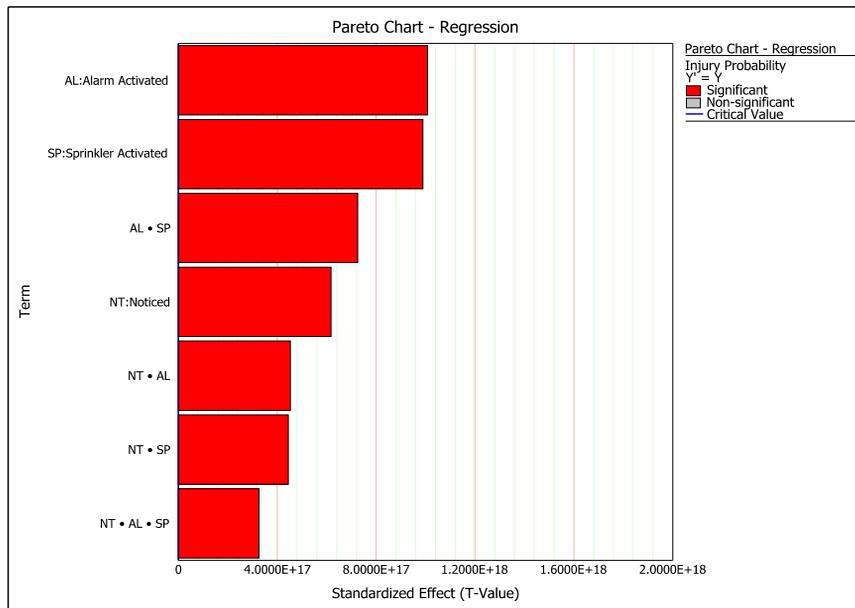


You return to DOE++ and refresh the simulation worksheet to display the response values that were generated from the flowchart simulation (i.e., the Injury probability for each combination of factors).

You then transfer the response data from the simulation worksheet to the design folio. When you analyze the data set (“*Injury from Fire*” in the sample project), you see that three of the four factors are significant, along with several interaction effects, as shown next.

Analysis Summary	
Significant Terms	
Term	Coefficient
NT:Noticed	-0.001200
AL:Alarm Activated	-0.001800
SP:Sprinkler Activated	-0.001795
NT • AL	0.001174
NT • SP	0.001170
AL • SP	0.001755
2 more...	

You use a Pareto chart to view the effects of the significant terms, as shown next.



From this plot, you determine that alarm activation and sprinkler system activation are the two main factors that influence injury.

3.10 Estimate the Baseline System Reliability



In this section, you will continue working with the “2. Chandelier - Assess Design Reliability” project in the quick start repository, using Xfmea/RCM++/RBI.

You return to Xfmea/RCM++/RBI to work with the Failure Modes and Reliability Analysis (FMRA) that you created earlier (see Section 3.7 on page 23). This time, you will use the reliability models that were obtained from the FMEA occurrence ratings to generate a preliminary estimate of the system's baseline reliability.

Assuming that any one of the FMEA causes could cause the component to fail (i.e., the causes are reliability-wise in series), the FMRA combines the cause reliabilities to get the reliability of each component. It then combines the component and assembly reliabilities until reaching the system level.

The following picture shows the reliabilities calculated from the “first draft” FMRA that is based solely on the information from the FMEAs. For a system operating time of 5,000 hours, the computed reliability for

the entire chandelier is about 84.95%. (This stage of the analysis is not visible in the sample project. The FMRA shown in the sample project reflects changes made during FMRA vetting, as explained next.)

System Hierarchy		FMRA	
Name		Reliability Policy	Reliability (Analytical)
Chandelier		Inherit	0.849499
Frame		Inherit	0.950943
Hold the Chandelier together		Inherit	0.950943
Frame Cracks, Falls		Inherit	0.950943
Corrosion		Corrosion	0.950990
Metal fatigue due to swinging, cyclical stresses		Metal fatigue due to swinging, cyclical stresses	0.999950
Wiring		Inherit	0.992525
Provide Electricity		Inherit	0.992525
Aging and Stress		Inherit	0.999500
Deterioration of the insulation		Deterioration of the insulation	0.999500
Bending		Inherit	0.995010
Tight bend radii		Tight bend radii	0.995010
Chafing		Inherit	0.999500
Swinging and looser wires		Swinging and looser wires	0.999500
Delamination		Inherit	0.999500
Failure of the bonding material		Failure of the bonding material	0.999500
Terminal point connection failure		Inherit	0.999500
Frequent manipulation		Frequent manipulation	0.999500
Series Arcing		Inherit	0.999500
Loose terminal or crimp, corrosion, or dirt in ...		Loose terminal or crimp, corrosion, or dirt in ...	0.999500
Bulb and Socket		Inherit	0.900051
Bulb		Inherit	0.922861
Provide light		Inherit	0.922861
Filament burns		Inherit	0.950990
Filament burns		Filament burns	0.950990
Bulb shatters		Inherit	0.990045
Overheat		Overheat	0.995010
Spike in voltage		Spike in voltage	0.995010
Base fails to make contact		Inherit	0.990040
Cap fails to screw all the way		Cap fails to screw all the way	0.990040
Insufficient light		Inherit	0.990040
Bulb wattage too low		Bulb wattage too low	0.990040
Socket		Inherit	0.975283
Provide electricity to bulb		Inherit	0.975283
Fails to make contact		Inherit	0.985100
Dirty contacts		Dirty contacts	0.995010
Solder connection failure		Solder connection failure	0.990040
Short		Inherit	0.990035
Presence of foreign conductive material		Presence of foreign conductive material	0.990040
Manufacturing		Manufacturing	0.999995

It is extremely important to note at this point that this first draft FMRA system reliability value may be nowhere close to the true reliability value. You now need to go back through the first draft FMRA and review each entry and the overall result. This is called *FMRA vetting*.



FMRA Vetting: In general, the FMRA vetting process involves these two steps:

- **Cleaning Up**
During this step, you review the failure causes that are being considered in the analysis and perform any cleanup that may be required to make sure the FMRA considers all the causes that impact the system's reliability, but does not consider causes that don't.
- **Reviewing and Validating Inputs**
During this step, you examine the calculated reliability estimates for each record to see if they fit your expectations. If not, you determine which inputs to the FMRA and DFMEAs might need to be revised with better information.

The ReliaWiki resource portal provides more information about the FMRA vetting process at: [http://www.ReliasWiki.org/index.php/Using FMRA to Estimate Baseline Reliability](http://www.ReliasWiki.org/index.php/Using_FMRA_to_Estimate_Baseline_Reliability).

When you begin to vet the first draft FMRA, the first thing you notice is that the “Bulb wattage too low” failure cause (which occurs if the user installs the wrong type of bulb) was something that needed to be considered during the FMEA, but it should not affect the chandelier's calculated reliability.

To prevent the software from considering this cause, you set the cause's reliability policy to **Define at this level** and remove the URD that was previously assigned to the cause. The software will assign a model with 100% reliability (“Default - Cannot Fail”), as shown next. (This is how it appears in the sample project).

Reliability Policy	
Type	Define at this level
URD	Default (Not Set)
Model	Default - Cannot Fail

This means that the cause record will essentially be ignored in the reliability calculations because the cause reliability will always be 100%.

When you recalculate the FMRA after making this change, you find that the system reliability changed to approximately 85.80% (as shown in the sample project).

You continue reviewing the rest of the analysis and make any updates that may be appropriate. Once vetted, the baseline reliability value is your initial design reliability. You will compare this with the target reliability, keeping in mind that this first baseline estimate is usually optimistic because you have not

accounted for other reliability contributors, including interactions. Furthermore, the product needs to go through manufacturing, and the manufacturing process will not increase the reliability. Thus, you want your initial baseline reliability value to exceed your reliability target value.

From a knowledge base viewpoint, it is also important to note that the FMEA and related FMRA should be updated continuously as new information becomes available, including the addition of new failure modes uncovered during testing as well as the revision of the underlying reliability models based on data obtained from testing. Upon the product's release, this process should continue with field information.

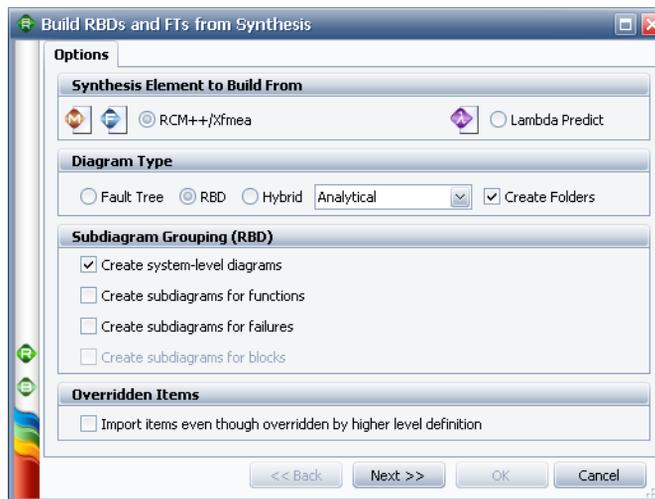
3.11 Identify Reliability Gaps



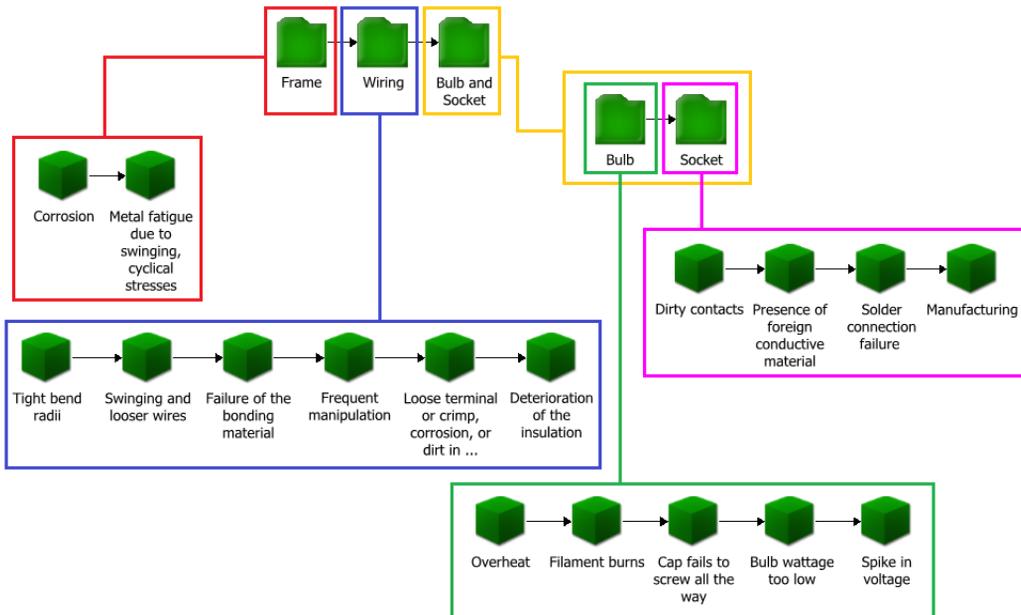
In this section, you will switch to the “3. Chandelier - Identify Reliability Gaps” project in the quick start repository, and perform the analysis using BlockSim.

Your next task is to perform a more advanced system analysis in order to better understand the system reliability and evaluate where to focus your efforts for improving the reliability.

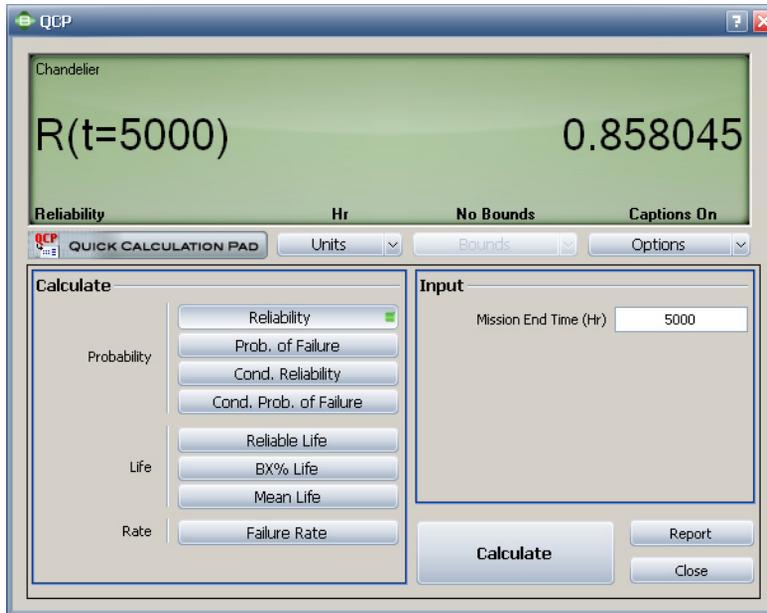
You open the project in BlockSim and use the **Build RBDs and FTs from Synthesis** utility to create a set of reliability block diagrams (RBDs) based on the latest information from the FMEAs and FMRA. The following picture shows the settings that were used to create these diagrams.



You open the main diagram, called “Chandelier,” which contains subdiagrams that represent the three assemblies. You then double-click each subdiagram to see its components. The following image shows all of the diagrams in relation to each other.



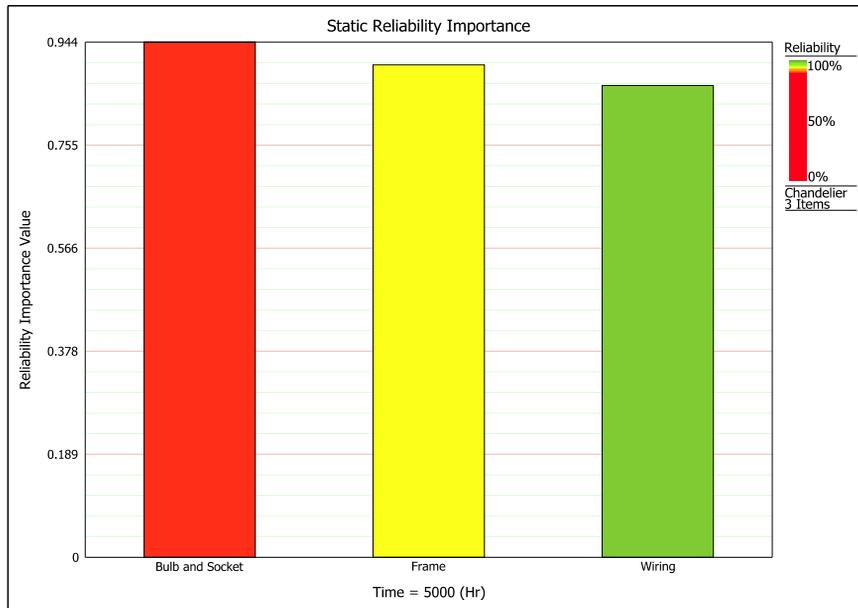
You analyze the main diagram and then choose **Analysis > Analytical QCP**. You see that BlockSim's QCP returns the same reliability result for $R(t=5,000)$ as the FMRA view in Xfmea/RCM++/RBI.



Now you want to investigate how to improve this number to get to the target reliability.

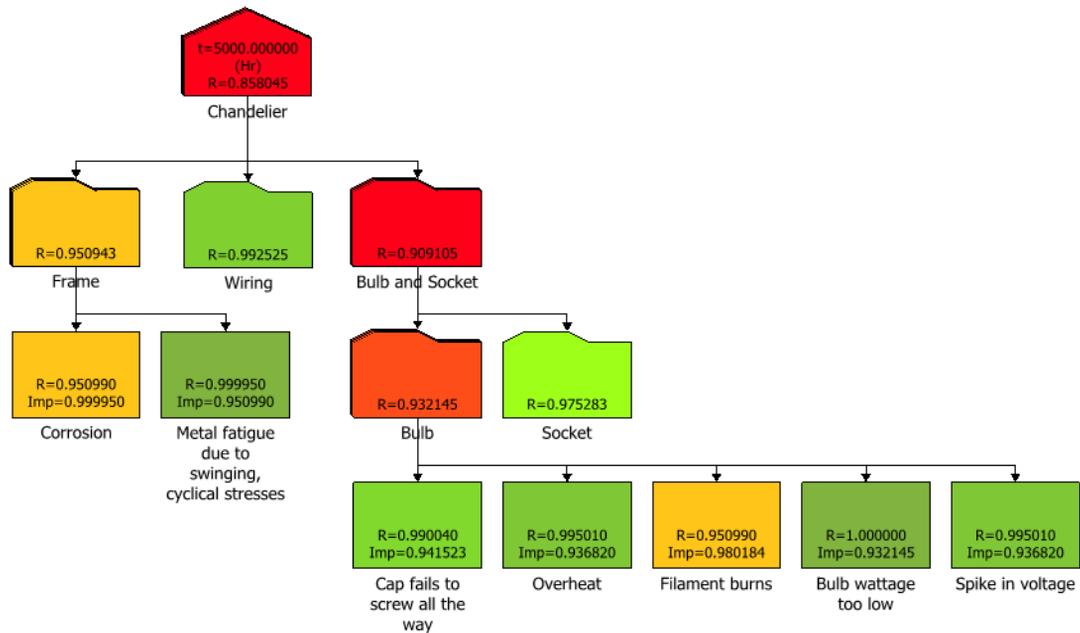
One approach is to start at the system level and look at the reliability importance of each assembly. Reliability importance is a measure of how much effect each assembly or component has on the overall

reliability of the system. The following picture shows the Static Reliability Importance plot for the “Chandelier” diagram (which is accessible from the Analytical Plot sheet in the diagram window).



You can view the same plot for the other diagrams, all the way down to the underlying causes.

Alternatively, BlockSim's FRED reports offer a less time-consuming and more readily understood approach. A FRED report can automatically trace the entire RBD structure and highlight the root causes from a reliability perspective, as shown next (*"FRED Report1" in the sample project*).



Here, all items with low reliability have been expanded to show the items that contribute to the problem.

- The Bulb and Socket assembly is clearly the primary unreliability driver. Within that assembly:
 - The Bulb is the major contributor.
 - The Bulb's primary root cause of failure is the tendency of the filament to burn.
- The secondary unreliability driver is the Frame assembly.
 - The Frame's primary root cause of failure is corrosion.

Having identified these root causes, the next course of action may be to question the FMEA team as to the reasons behind each cause. This more advanced look at the FMEA, through a system reliability focus, highlights items that need further attention and investigation, and items that need to be addressed in order to meet the target reliability.

You can also use the BlockSim diagrams to determine the target reliability for these assemblies and failure causes of interest. To do this, you add an allocation analysis (*"Allocation Analysis" in the sample project*), based on the Chandelier diagram. On the control panel, you change the inputs to reflect the goal of 95% reliability at 5,000 hours and choose the **cost optimized** allocation type. You change the color limits to

85%-100% to make the analysis easier to read, and you clear the check box for the Wiring assembly, because the causes of interest (as determined via the reliability importance plot and/or the FRED report) do not relate to that assembly. The resulting allocation analysis is shown next.

<input type="checkbox"/>	Block Name	Reliability Importance	Current Reliability	Maximum Achievable Reliability	Feasibility	Target Reliability	Equivalent Parallel Units
<input checked="" type="checkbox"/>	Frame	0.902310	0.950943	1	Easy (1)	0.982068	1.333824
<input checked="" type="checkbox"/>	Wiring	0.864507	0.992525	1	Easy (1)	-	-
<input checked="" type="checkbox"/>	Bulb and Socket	0.943835	0.909105	1	Easy (1)	0.974632	1.532178

Calculations

ALLOCATION ANALYSIS

Allocation Type: **Cost Optimized**

Refresh

Inputs

Target Reliability: **0.95**

Time: **5000**

Units: **Hour (Hr)**

Iterations: 50

Outputs

Current Reliability: 0.858045

System Reliability: 0.950000

Color Limits

85.00 % - 100.00 %; Full

Chandelier

To view more specific results on the Frame assembly, you click its name in the table. This adds an additional allocation analysis to the folio with the target reliability already in place. The current reliability

for the “Metal fatigue” cause is already almost 100%, so you clear the check box for that cause. The calculated allocation analysis for the Frame assembly is shown next.

<input checked="" type="checkbox"/>	Block Name	Reliability Importance	Current Reliability	Maximum Achievable Reliability	Feasibility	Target Reliability	Equivalent Parallel Units
<input checked="" type="checkbox"/>	Corrosion	0.999950	0.950990	1	Easy (1)	0.982116	1.334288
<input type="checkbox"/>	Metal fatigue due to swinging, cyclical stresses	0.950990	0.999950	1	Easy (1)	-	-

The Corrosion cause was one of the causes of interest identified in the FRED report. In the Target Reliability column for this cause, you see that the reliability value that should be achieved for the Corrosion cause, in order for the Frame assembly to reach its target reliability, is about 98.21%.

You then return to the Chandelier tab and click the name of the Bulb and Socket assembly to create an allocation analysis for it, as shown next.

Block Name	Reliability Importance	Current Reliability	Maximum Achievable Reliability	Feasibility	Target Reliability	Equivalent Parallel Units
Bulb	0.975283	0.932145	1	Easy (1)	0.983673	1.529488
Socket	0.932145	0.975283	1	Easy (1)	0.990809	1.267359

You will recall that the Bulb was the main contributor to the unreliability of this assembly. Because the Bulb is a component that you purchase, you do not need to examine it at the cause level; a single target reliability for the component is sufficient. The value shown in the Target Reliability column for the Bulb is about 98.37%. The Socket was not a significant contributor to unreliability and does not require further analysis.

3.12 Improve the Reliability



In this section, you will work with the “4. Chandelier - Improve Reliability” project in the quick start repository. Some of the steps are performed in Weibull++/ALTA and some in Xfmea/RCM++/RBI.

With the primary root causes identified, the team can now focus on increasing the reliabilities of these specific items in order to assure that the target will be met. To do this, you expand the analysis to include models created from data.

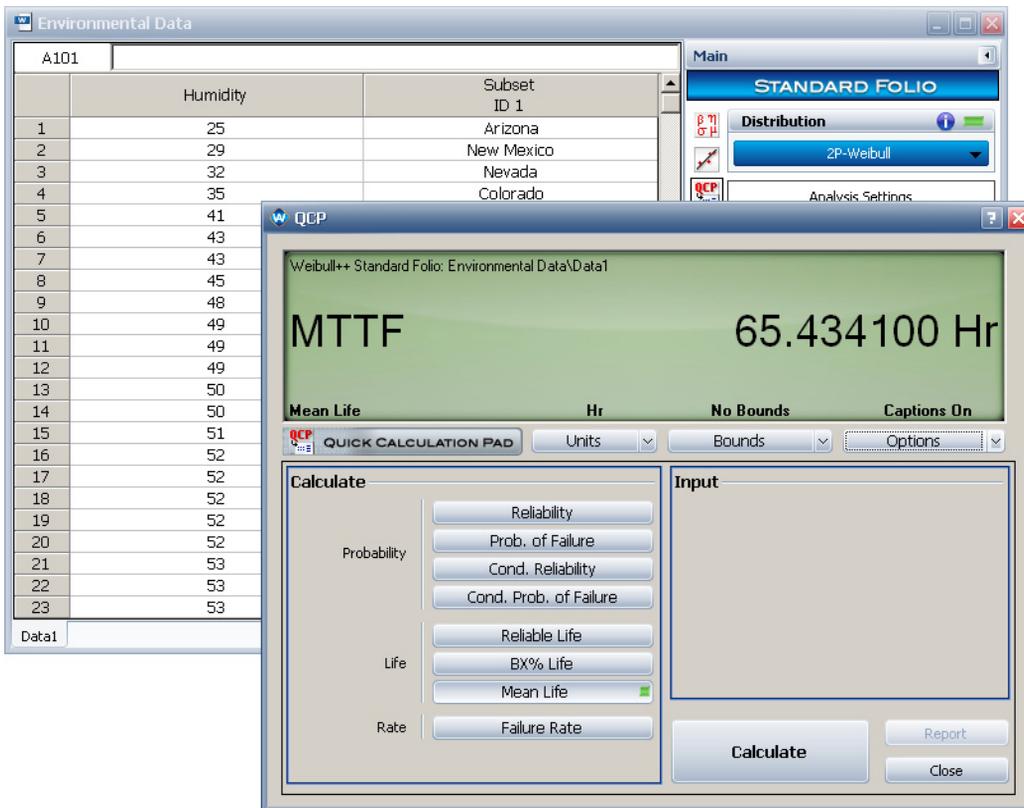
Up to this point, the models and modeling assumptions used have been fairly simplistic and based on the qualitative values entered in the DFMEA. As the design effort progresses, these reliability estimates can be replaced with more robust estimates. These could be based on actual test data, reliability growth data,

simulations, etc. By performing these analyses in other Synthesis applications, you can create newer quantitative models to replace the first cut approximation.

For example, as you saw in the allocation analysis, the current reliability associated with the Corrosion cause is about 95.10%. This indicates that corrosion occurs in about 5 out of every 100 items. You determined in the allocation analysis that this needs to be improved to 98.21%, or approximately 18/1,000. To address this, you proceed with the accelerated corrosion test requested by the FMEA team (*see Section 3.6 on page 21*).

WEIBULL++ ALTA

You perform an analysis of humidity readings from throughout the country in Weibull++ (*“Environmental Data” in the sample project*), based on the data in the Excel file attached to the project plan. Then you use the QCP to obtain the mean humidity value, as shown next.



The screenshot displays the Weibull++ software interface. On the left, an Excel spreadsheet titled "Environmental Data" shows humidity readings for various locations. The data is as follows:

Humidity	Subset ID 1
25	Arizona
29	New Mexico
32	Nevada
35	Colorado
41	
43	
43	
45	
48	
49	
49	
49	
50	
50	
51	
52	
52	
52	
52	
52	
53	
53	
53	

The QCP (Quick Calculation Pad) window is open, showing the following results:

- MTTF:** 65.434100 Hr
- Mean Life:** Hr
- Bounds:** No Bounds
- Captions:** On

The QCP window also features a "QUICK CALCULATION PAD" with various calculation options:

- Probability:** Reliability, Prob. of Failure, Cond. Reliability, Cond. Prob. of Failure
- Life:** Reliable Life, BX% Life, Mean Life (checked)
- Rate:** Failure Rate

Buttons for "Calculate", "Report", and "Close" are visible at the bottom of the QCP window.

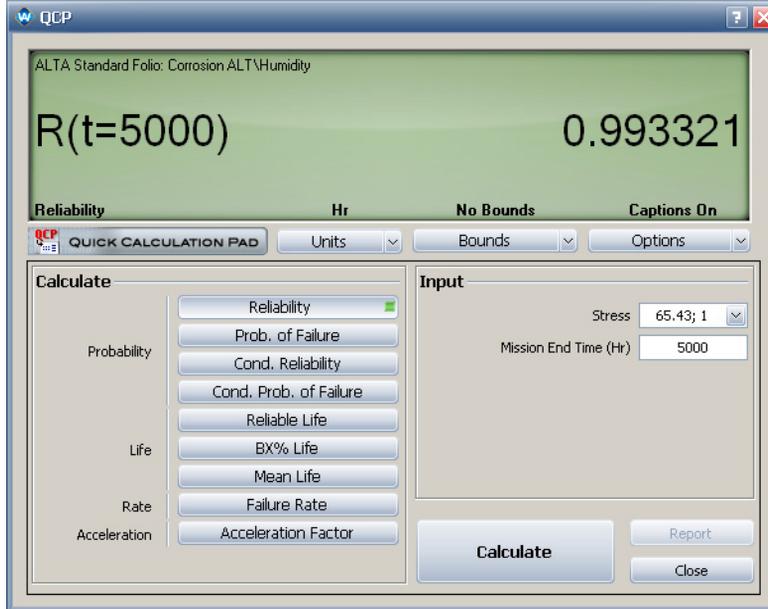
Next, you perform the accelerated life testing for frame corrosion that was requested. Using the mean humidity value you just obtained as the use stress for humidity, you then analyze the data in an ALTA standard folio (“Corrosion ALT” in the sample project).

The screenshot displays the 'Corrosion ALT' software interface. The main window is titled 'A50' and contains a data table with the following columns: Number in State, State F or S, State End Time, Humidity RH, Chemical x Times Normal, and Subset ID 1. The data rows are numbered 1 through 33. The 'Humidity' column has a checkmark in the header, and the 'Chemical' column has a checkmark in the header. The 'State End Time' column contains values ranging from 147 to 720. The 'Humidity RH' column contains values of 80, 95, and 95. The 'Chemical x Times Normal' column contains values of 2, 3, and 3. The 'Subset ID 1' column is empty.

On the right side of the interface, there is a 'Main' panel titled 'STANDARD FOLIO'. It contains a 'Model' section with a dropdown menu set to 'GLL-Weibull'. Below this are links for 'Select Stress Columns...', 'Stress Transformation...', and 'Set Use Stress...'. The 'Analysis Summary' section includes 'Parameters' (Beta: 3.095272), 'Alpha' (Alpha(0) (Hr): 12.236179, Alpha(1): -0.082531, Alpha(2): 3.298163), 'Scale Parameter (at Use Stress)' (Eta (Hr): 25193.269498), and 'Other' (LK Value: -101.843247). The 'Use Stress' section shows 'Humidity: 65.43' and 'Chemical: 1'. The 'Failures/Suspensions' section shows 'F/S: 15/15'. The 'Publishing' section shows 'Model: Synchronized'. The 'Comments' section is empty.

	Number in State	State F or S	State End Time	Humidity RH	Chemical x Times Normal	Subset ID 1
1	1	F	587	80	2	
2	1	F	698	80	2	
3	10	S	720	80	2	
4	1	F	358	80	3	
5	1	F	450	80	3	
6	1	F	615	80	3	
7	5	S	720	80	3	
8	1	F	187	95	2	
9	1	F	277	95	2	
10	1	F	349	95	2	
11	1	F	419	95	2	
12	1	F	498	95	2	
13	1	F	611	95	2	
14	1	F	147	95	3	
15	1	F	158	95	3	
16	1	F	214	95	3	
17	1	F	312	95	3	
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
32						
33						

Using the QCP to calculate the reliability at 5,000 hours, you get a result of 99.33%.



You publish the model, as shown next, to make it available for subsequent use in the FMRA.

The screenshot shows the Synthesis software interface. The main window is titled 'Corrosion ALT' and contains a table with the following data:

	Number in State	State F or S	State End Time	Humidity RH	Chemical x Times Normal	Subset ID 1
1	1	F	587	80	2	
2	1	F	698	80	2	
3	10	S	720	80	2	
4	1	F	358	80	3	
5	1	F	450	80	3	
6	1	F	615	80		
7	5	S	720	80		
8	1	F	187	95		
9	1	F	277	95		
10	1	F	349	95		
11	1	F	419	95		
12	1	F	498	95		
13	1	F	611	95		
14	1	F	147	95		
15	1	F	158	95		
16	1	F	214	95		
17	1	F	312	95		
18						
19						
20						
21						
22						
23						

The 'Publish Model' dialog box is open, showing the following details:

- Model Name:** ALTA_Corrosion
- Model Category:** Reliability
- Model Properties:**
 - Distribution:** GLL-Weibull
 - Parameters and Inputs:**
 - Beta: 3.095272
 - Alpha(0): 12.236179
 - Alpha(1): -0.082531
 - Alpha(2): 3.298163
 - Units: Hour
 - Use Stress: 65.43; 1
 - Identifiers:**
 - Category: No Category

Another issue is bulb reliability. In this case, your team considers three bulb models (61A, 69C and A14) for use in the chandelier, as requested by the FMEA team (see Section 3.6 on page 21).

For model A14, you perform an accelerated life test and analyze the data in an ALTA standard folio (“*Bulb Model A14*” in the sample project).

The screenshot displays the Synthesis Platform interface. The main window is titled "Bulb Model A14" and contains a data table with the following columns: "State F or S", "Time to F or S (Hr)", "Voltage V", and "Subset ID 1". The table lists 16 data points, with rows 1 through 16 containing numerical values and rows 17 through 30 being empty. The "Voltage V" column has a checkmark in its header cell.

To the right of the table is a "STANDARD FOLIO" analysis summary panel. It includes a "Model" dropdown set to "IPL-Waibull", buttons for "Select Stress Columns...", "Stress Transformation...", and "Set Use Stress...", and an "Analysis Summary" section with the following parameters:

Parameters	
Beta	4.418862
K (Hr)	3.518474E-27
n	10.713257
Scale Parameter (at Use Stress)	
Eta (Hr)	15095.343515
Other	
LK Value	-104.769069
Use Stress	
Voltage	120
Failures/Suspensions	
F/S	13/3
Publishing	
Model	Synchronized
Comments	

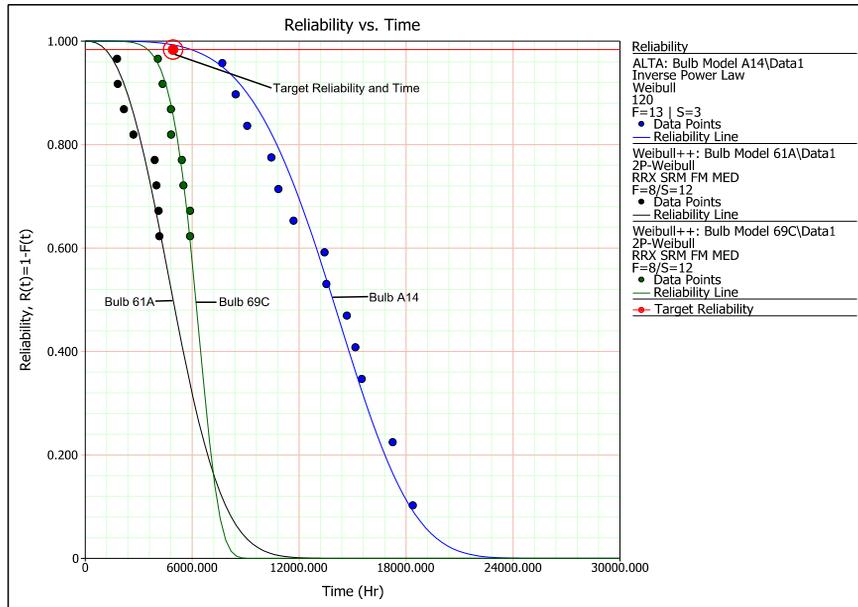
At the bottom of the interface, there is a "Main" section with an "Analysis" button and several status icons.

For the other two bulbs (61A and 69C), you perform traditional life tests and analyze the data with Weibull++ standard folios (*“Bulb Model 61A”* and *“Bulb Model 69C”* in the sample project).

The screenshot displays two software windows for bulb analysis. The top window, 'Bulb Model 61A', shows a data table with columns for Number in State, State (F or S), State End Time (Hr), and Subset ID 1. The bottom window, 'Bulb Model 69C', shows a similar table with columns for State (F or S), Time to F or S (Hr), and Subset ID 1. To the right, a 'Main' window displays the 'STANDARD FOLIO' interface, including a 'Distribution' dropdown set to '2P-Weibull', 'Analysis Settings' (RRX, SRM, FM, MED), and an 'Analysis Summary' section with parameters: Beta (2.548513), Eta (Hr) (5696.777191), Rho (0.927413), and LK Value (-78.542747). The bottom 'Main' window shows parameters: Beta (6.590177), Eta (Hr) (6563.216644), Rho (0.969224), and LK Value (-75.347962).

You then create an overlay plot (*“Bulb Testing”* in the sample project) that shows how the reliabilities of the bulbs compare. You will recall that the results of the allocation analysis, shown on page 47, gave a

target reliability for the Bulb of 98.37% at 5,000 hours. This target reliability is marked on the overlay plot, as shown next. (Note that labels have been added here for clarity.)



You can see that only bulb A14 meets the target requirement, so you recommend that A14 be used in the design.

You publish the model for the selected bulb, A14, as shown next.

The screenshot displays the SYNTHESIS software interface. In the background, a data table titled 'Bulb Model A14' is visible, showing columns for State (F or S), Time to F or S (Hr), Voltage V, and Subset ID 1. The 'Publish Model' dialog box is open, showing the following details:

Model Name		Model Category
ALTA_Bulb Model A14		Reliability

Model Properties

- Distribution:** IPL-Weibull
- Parameters and Inputs:**
 - Beta: 4.418862
 - K: 3.518474E-27
 - n: 10.713257
 - Units: Hour
 - Use Stress: 120
- Identifiers:**
- History:**

At the bottom of the dialog, it indicates 'Used by 1 item' and includes 'OK' and 'Cancel' buttons.



You then return to Xfmea/RCM++/RBI and use the models that you have just published to describe the probability of the Corrosion cause and the reliability of the Bulb. First, you change the cause's reliability policy type to **Define at this level** and select the corrosion model in the **Model** field.

Properties	
Property Name	Value
Cause	
Failure Mode	Corrosion
Name	*
Keywords	
Initial Occurrence	6 - 1 in 100 ▼
Revised Occurrence	6 - 1 in 100 ▼
Initial Detection	5 - Medium ▼
Revised Detection	5 - Medium ▼
Reliability / Availability	
Reliability Policy	
Type	Define at this level ▼
URD	Corrosion ...
Model	ALTA_Corrosion [GLW (3.1, 12.2, -0.0825, 3.3)] ▼
Corrective Task	Default - Cannot Be Repaired
History	
Cause	

You do the same for the Bulb, replacing the reliability estimate that was calculated by rolling up the probabilities for the failure causes.

Properties	
Property Name	Value
Identifiers	
Image	
Name	Bulb
Category	No Category
Part Number	A14
Supplier	Bulbs R Us
Application	Residential use
Description	Specialized custom bulb designed to last 5,000 hours or more.
Comments	
Keywords	
Other Item Properties	
Operation	
Operating Time	5000 (Hr)
Current Age	0 (Hr)
Duty Cycle	1
Maintenance Group	
Reliability Policy	
Type	Define at this level
URD	Bulb_URD
Model	ALTA_Bulb Model A14 [IPW (4.42, 3.52E-27, 10.7)]
Corrective Task	Default - Cannot Be Repaired
Reliability / Availability	
Push to Metrics	
History	
<input type="checkbox"/> Item	

When you recalculate the FMRA, you see that the reliability value associated with the Corrosion cause at 5,000 hours is now about 99.33%, which is more than good enough to meet the goal of 98.21% that was determined in the allocation analysis. Similarly, the Bulb's reliability at 5,000 hours is now 99.25%, which exceeds the goal of 98.37%.

The overall reliability of the chandelier with these changes is now approximately 95.42%, which meets the target reliability.

3.13 Consider a Design Change



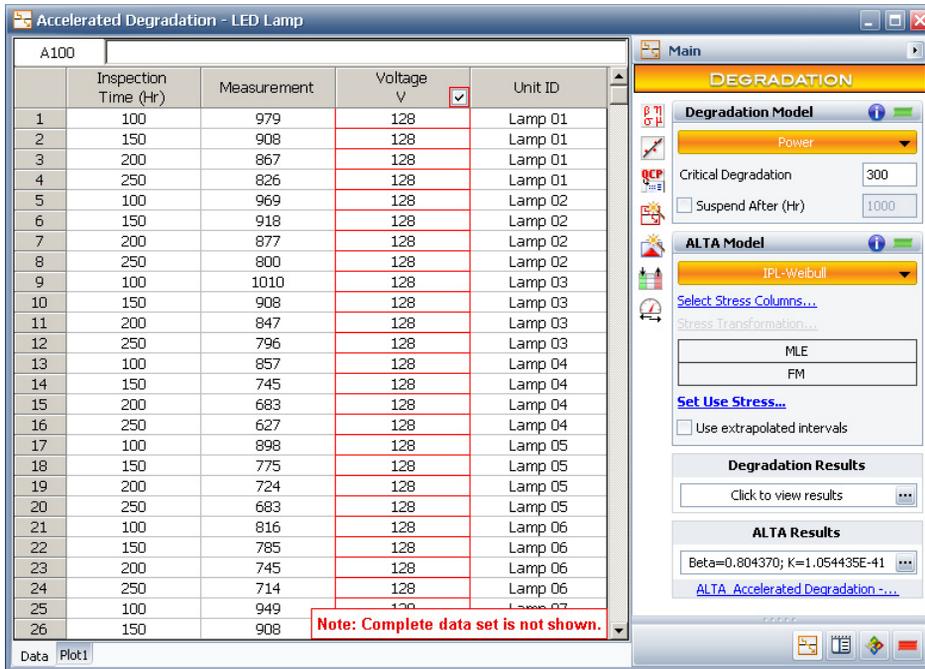
In this section, you will switch to the “4a. Chandelier - Design Change” project in the quick start repository. Some of the steps are performed in ALTA, some in Lambda Predict and some in Xfmea/RCM++/RBI.

At this point, your company considers the possibility of developing a new chandelier model that uses a dimmable LED light source, in order to keep up with the latest technology on the market. This model would use the existing design, except the incandescent bulb would be replaced with a commercial off-the-shelf LED bulb, and an LED controller would be added.

An accelerated test has provided some degradation data for the LED bulb that you can analyze in ALTA. You decide to use the Telcordia reliability prediction standard in Lambda Predict to calculate a predicted failure rate for the controller.

ALTA

First, you duplicate your project so that you can make changes to the system without losing your original work. In the new project, you perform the accelerated degradation analysis (“*Accelerated Degradation - LED Lamp*” in the sample project) in ALTA, as shown next, and publish the model.



	Inspection Time (Hr)	Measurement	Voltage V	Unit ID
1	100	979	128	Lamp 01
2	150	908	128	Lamp 01
3	200	867	128	Lamp 01
4	250	826	128	Lamp 01
5	100	969	128	Lamp 02
6	150	918	128	Lamp 02
7	200	877	128	Lamp 02
8	250	800	128	Lamp 02
9	100	1010	128	Lamp 03
10	150	908	128	Lamp 03
11	200	847	128	Lamp 03
12	250	796	128	Lamp 03
13	100	857	128	Lamp 04
14	150	745	128	Lamp 04
15	200	683	128	Lamp 04
16	250	627	128	Lamp 04
17	100	898	128	Lamp 05
18	150	775	128	Lamp 05
19	200	724	128	Lamp 05
20	250	683	128	Lamp 05
21	100	816	128	Lamp 06
22	150	785	128	Lamp 06
23	200	745	128	Lamp 06
24	250	714	128	Lamp 06
25	100	949	128	Lamp 07
26	150	908	128	Lamp 07

Note: Complete data set is not shown.



In Lambda Predict, you perform the reliability prediction (“Dimmer Controller” in the sample project), as shown next.

The screenshot shows the 'Dimmer Controller' system hierarchy and its properties. The system hierarchy table is as follows:

Name	Category	Quantity	Failure Rate(t=INF)
Dimmer Controller	Telcordia SR-332 Issue 3	1	93,7130 FITs
TRIAC Dimmer Dection Block	Block	1	21,7136
ZD1	Diode	1	1,5265
ZD2	Diode	1	1,3539
R1	Resistor, Fixed	1	0,1766
R2	Resistor, Fixed	1	0,1926
TR1, TR2	Transistor	2	8,8010
INV1	IC, Digital	1	4,1247
SR Gate	IC, Digital	1	4,1247
VCMP1	IC, Analog/Linear	2	1,4136
Dimming Control Block	Block	1	29,6423
TR3, TR4	Transistor	2	18,0810
R5	Resistor, Fixed	1	0,1926
AMP1	IC, Analog/Linear	3	2,8766
EXDim	IC, Digital	1	4,4084
R3	Resistor, Fixed	1	0,2497
R4	Resistor, Fixed	1	0,2137
C1	Capacitor	1	1,3721
C2	Capacitor	1	1,0866
R6, R7	Resistor, Fixed	1	0,2028
AMP2	IC, Analog/Linear	1	0,9589
PWM block	Block	1	42,3572
TR5	Transistor	1	9,0405
OCP	IC, Analog/Linear	1	0,9589
PWMCMP	IC, Analog/Linear	1	0,9589

The Properties panel shows the following values:

Properties	Values
Name	Dimmer Controller
ID	
Part Number	
Alternate Part Number	
Version	
LCN	
Reference Designator	
Supplier	
Application	
Description	
Function Description	
Redundancy	False
Quantity	1
Quantity Required	1
Mission Time (hrs)	24
Analyst	
Compiled By	
Approved By	
Comments	

You publish the model for the Dimmer Controller system by selecting the system and choosing **Prediction Tools > Share > Publish Item Model**.



You then open this project in Xfmea/RCM++/RBI and change the system hierarchy to include the Controller and LED Bulb, as shown next.

Name				
Chandler				
Frame		▲	2	F
Wiring		▲	4	F
LED and Controller				
Integrated Dimming LED				
Lighting Controller				
LED Light				
Socket		▲	2	F

In the FMRA view, you use the ALTA model that you published to describe the reliability of the LED light.

Reliability Policy	
Type	Define at this level
URD	LED Light_URD
Model	ALTA_Accelerated Degradation - LED Lamp [IPW (0.804, 1.05E-41, 17.2)]

You use the model from Lambda Predict to describe the reliability of the controller.

Reliability Policy	
Type	Define at this level
URD	Integrated Dimming LED Lighting Controller_URD
Model	LP_Dimmer Controller [EX1 (9.37E-08)]

Calculating the FMRA, you see that the reliability estimate for the LED version of the chandelier is about 90.41%, as shown next.

Name	Reliability Policy	Reliability (Analytical)
Chandelier	Inherit	0.904140
Frame	Inherit	0.993272
Wiring	Inherit	0.992525
LED and Controller	Inherit	0.917120
Integrated Dimming LED Lighting Controller	Integrated Dimming LED Lighting Controller_URD	0.999532
LED Light	LED Light_URD	0.940804
Socket	Inherit	0.975283
Provide electricity to bulb	Inherit	0.975283
Fail to make contact	Inherit	0.985100
Dirty contacts	Dirty contacts	0.995010
Solder connection failure	Solder connection failure	0.990040
Short	Inherit	0.990035
Presence of foreign conductive material	Presence of foreign conductive material	0.990040
Manufacturing	Manufacturing	0.999995

This represents a significant decrease in reliability from the version of the chandelier that uses the incandescent bulb, which had an estimated reliability of 95.42%. The company decides to shelve the plans for the LED design temporarily, and you return your focus to the original design.

3.14 Testing and Ongoing Product Development

(Note that the steps described in this section are not visible in the sample project.)

Throughout the rest of the chandelier's life cycle, you will continue to perform tests and other activities to quantify and improve the reliability of your product. You will use XFRACAS (a web-based failure reporting analysis and corrective action system) to record and manage information about new failure

modes and issues that are discovered, as well as about the actual occurrence of failure modes that were anticipated in the FMEA.

As new information becomes available, you will analyze the data to publish new models and update existing ones. The data can be obtained from a variety of channels, including testing, field performance and data sets extracted from XFRACAS. At any time, you can pull data for one or more parts from XFRACAS into the Synthesis Data Warehouse (SDW). From there, you can transfer the data set into Weibull++ or ALTA for life data analysis and/or into RGA for reliability growth analysis.

The screenshot displays two overlapping software windows. The top window, titled 'XFRACAS to SDW', has a sidebar with 'WEIBULL++' and 'ALTA' logos. Its main area is titled 'Entity' and shows 'RELIASOFT MODEL DATABASE'. Below this is a 'Select Parts' table with columns for Part Number, Part Name, and Part Version. The table lists several parts, including 'C1' (Chandler), 'FRC1' (Composite Frame), 'WR1' (Wiring), and 'BS3' (FL Bulb and Socket). The bottom window is titled 'Synthesis Data Warehouse' and features a toolbar with various icons for data management and viewing. Below the toolbar is a 'Data Source Manager' on the left and a data table on the right. The data table has columns for 'Include in Analysis?', 'StateTime', 'StateFS', 'TopLevelSerialNu...', and 'LastInspectedTime'. The table contains 15 rows of data, with some rows highlighted in green (Include) and others in red (Invalid). The bottom row is labeled 'Ignore'.

Include in Analysis?	StateTime	StateFS	TopLevelSerialNu...	LastInspectedTime
Include	63753	S	2	63753
Include	1444	S	2	1444
Include	22161	S	2	22161
Include	19906	S	2	19906
Include	5888	S	3	5888
Include	72275	S	3	72275
Invalid	-76663	S	3	-76663
Include	18961	S	4	18961
Include	76757	F	4	76757
Invalid	-94240	S	4	-94240
Include	48799	S	5	48799
Include	19968	S	5	19968
Include	47013	S	5	47013
Include	83482	S	6	83482
Include	447	F	6	447
Ignore	0	S	6	0

You can also use the XFRACAS data to improve the FMEA and maintenance plans. This includes adding new failure modes that have been observed during testing and/or in the field, as well as improving the accuracy of occurrence ratings based on the number of times that failure modes actually occurred.

3.15 Maintenance Planning

The system configuration and reliability information that you have developed from prior analyses can easily be adopted for life cycle cost and maintenance planning in BlockSim and RCM++/RBI. In this case,

you decide to estimate the availability and maintenance costs that your customers are likely to experience after purchasing and installing your new chandelier. You expect that customers will replace the chandelier entirely if there are problems with the frame or the wiring. They will replace burned-out bulbs themselves, but will need to call an electrician for socket issues.

3.15.1 Defining Reliability Models at the Component/Assembly Level



In this section, you will switch to the “5. Chandelier - Maintenance Planning Part 1” project in the quick start repository, using BlockSim.

For prior analyses, the system hierarchy and the DFMEA went down to specific root causes to determine actions to improve reliability and to define reliability design targets for specific failure modes. This makes sense during development. From a reliability-based maintenance perspective, however, information on the causes or failure modes may need to be less detailed, because the actions to address the failures would be at a higher level. For example, regardless of what caused the bulb to fail, the entire bulb must be replaced to restore the system. Addressing causes below the bulb failure level adds no value in this case, as the resulting action would be identical. Thus, the reliability does not need to be inherited from the underlying causes, but rather can be defined at the component/assembly level.

So the next step is to assign reliability models for the Frame, Wiring, Bulb and Socket, which can then be used for maintenance planning. To do this, you return to the same FMRA analysis that you created in Xfmea/RCM++/RBI, but now you will work with the analysis in BlockSim. Editing the same FMRA in both applications is like having the same document open in two software windows. Any changes that are made in one location will be applied to the other when you synchronize the two.

Note: Since they are directly linked, any changes made in the FMRA are also made in the FMEA. For example, if you delete a block that represents a cause from the FMRA view in BlockSim, this will automatically delete it from both the FMRA and the associated FMEA in Xfmea/RCM++/RBI. The same holds true when you change properties, etc. For this reason, it is important to exercise caution in this environment.

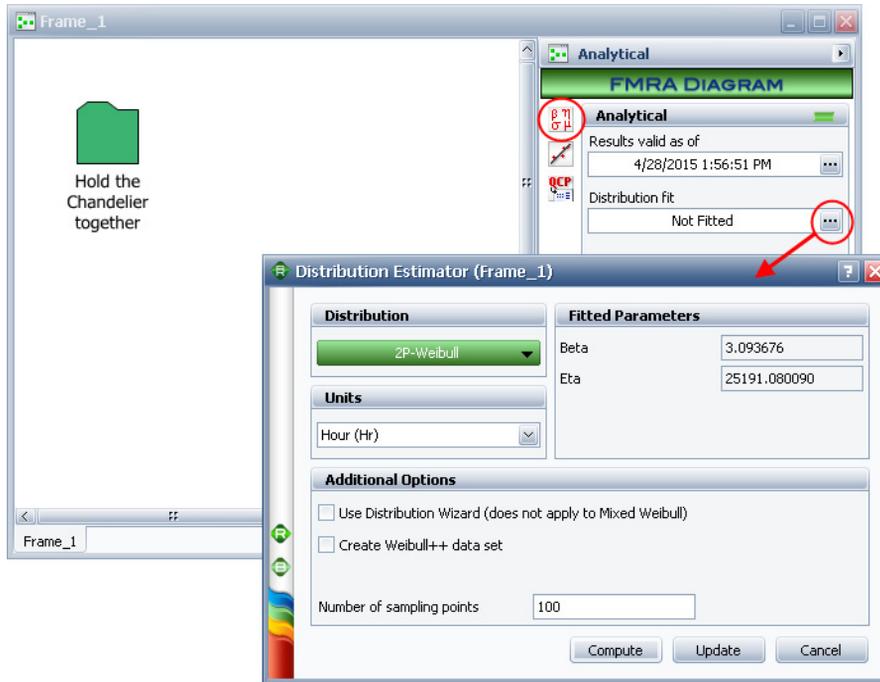
If the FMRA tab is not already visible when you open the sample project in BlockSim, choose **View > Show > Show FMRA** to display it. You can see that the reliability of the Bulb is now obtained from the accelerated life testing data analysis that you performed in ALTA, while the reliabilities of the Frame,

Wiring and Socket are still being “inherited” from the failure mode occurrence models obtained from the FMEAs.

Name	Reliability Policy
Chandelier	Inherit
Frame	Inherit
Hold the Chandelier together	Inherit
Frame Cracks, Falls	Inherit
Corrosion	Corrosion
Metal fatigue due to swinging, cyclical stresses	Metal fatigue due to swinging, cyclical stresses
Wiring	Inherit
Provide Electricity	Inherit
Aging and Stress	Inherit
Deterioration of the insulation	Deterioration of the insulation
Bending	Inherit
Tight bend radii	Tight bend radii
Chafing	Inherit
Swinging and looser wires	Swinging and looser wires
Delamination	Inherit
Failure of the bonding material	Failure of the bonding material
Terminal point connection failure	Inherit
Frequent manipulation	Frequent manipulation
Series Arcing	Inherit
Loose terminal or crimp, corrosion, or dirt in ...	Loose terminal or crimp, corrosion, or dirt in ...
Bulb and Socket	Inherit
Bulb	Bulb_URD
Socket	Inherit
Provide electricity to bulb	Inherit
Fails to make contact	Inherit
Dirty contacts	Dirty contacts
Solder connection failure	Solder connection failure
Short	Inherit
Presence of foreign conductive material	Presence of foreign conductive material
Manufacturing	Manufacturing

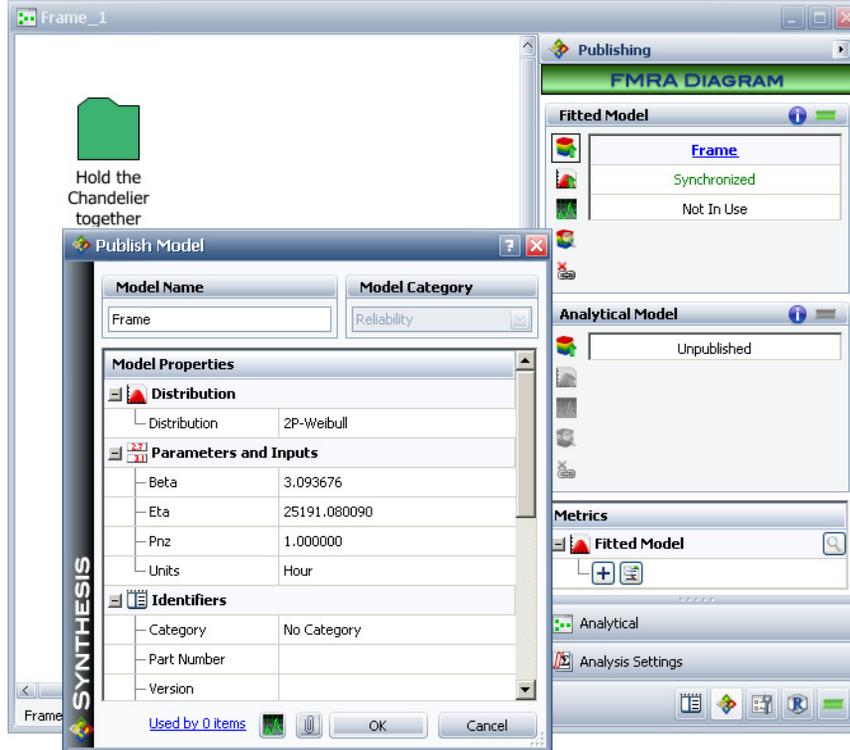
To obtain a reliability model that can be applied directly to the Frame, you first double-click the item in the FMRA hierarchy to see its reliability block diagram. Then you analyze the diagram and use the

Distribution Estimator to fit a model that represents the entire assembly. The following picture shows the results.



Then you go to the Publishing page of the diagram's control panel and publish this fitted model as a

Synthesis resource that represents the reliability of the Frame.



You follow a similar process to create and publish models for the Wiring and Socket. (To see these diagrams in the sample project, double-click each item in the FMRA hierarchy.)

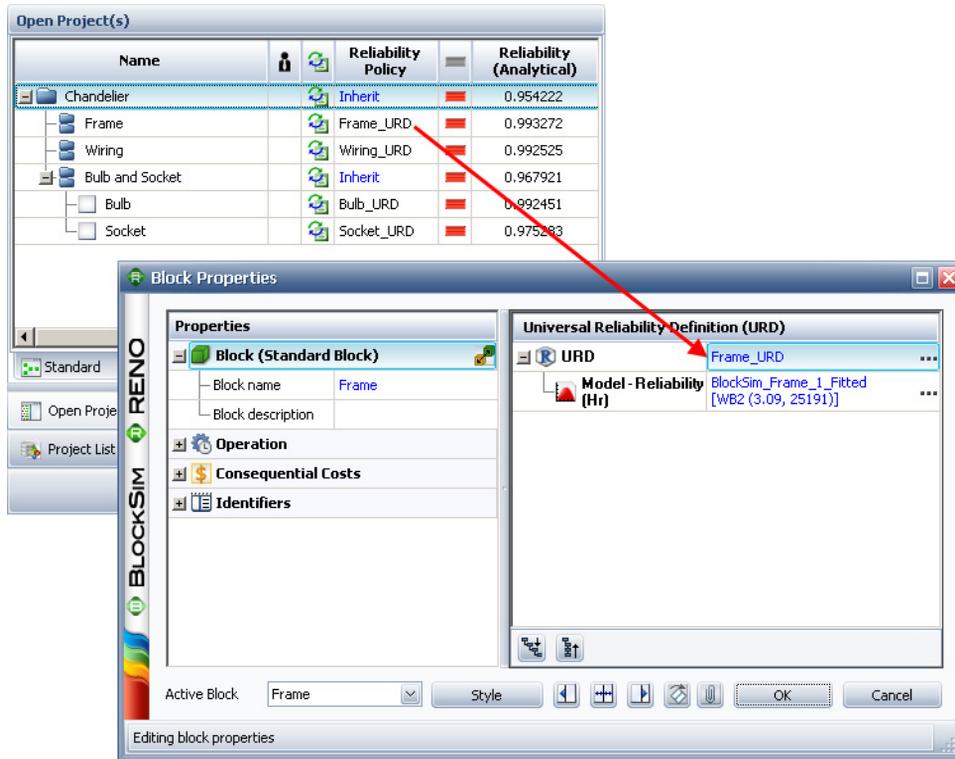
3.15.2 Assigning the Models in the FMRA



In this section, you will switch to the “6. Chandelier - Maintenance Planning Part 2” project in the quick start repository, still using BlockSim.

To use the new published models in the FMRA, you select each item and choose **FMRA > Inheritance > Define at this level**. This turns the item from a diagram (in which the reliability was calculated from sub-items and/or failure modes) into a single block. You then double-click the item to open the block

properties and assign the published reliability model. The following picture shows the updated FMRA, as well as the model that has now been assigned to the Frame block.



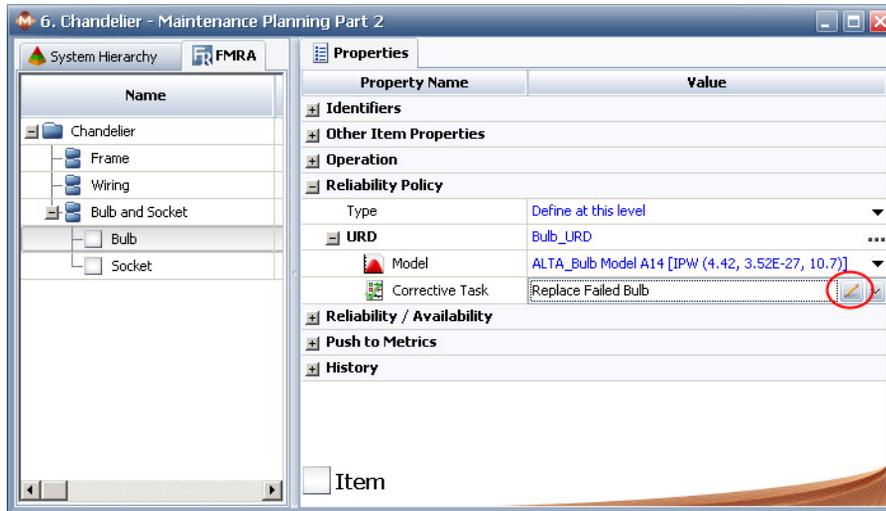
3.15.3 Creating the Maintenance Tasks



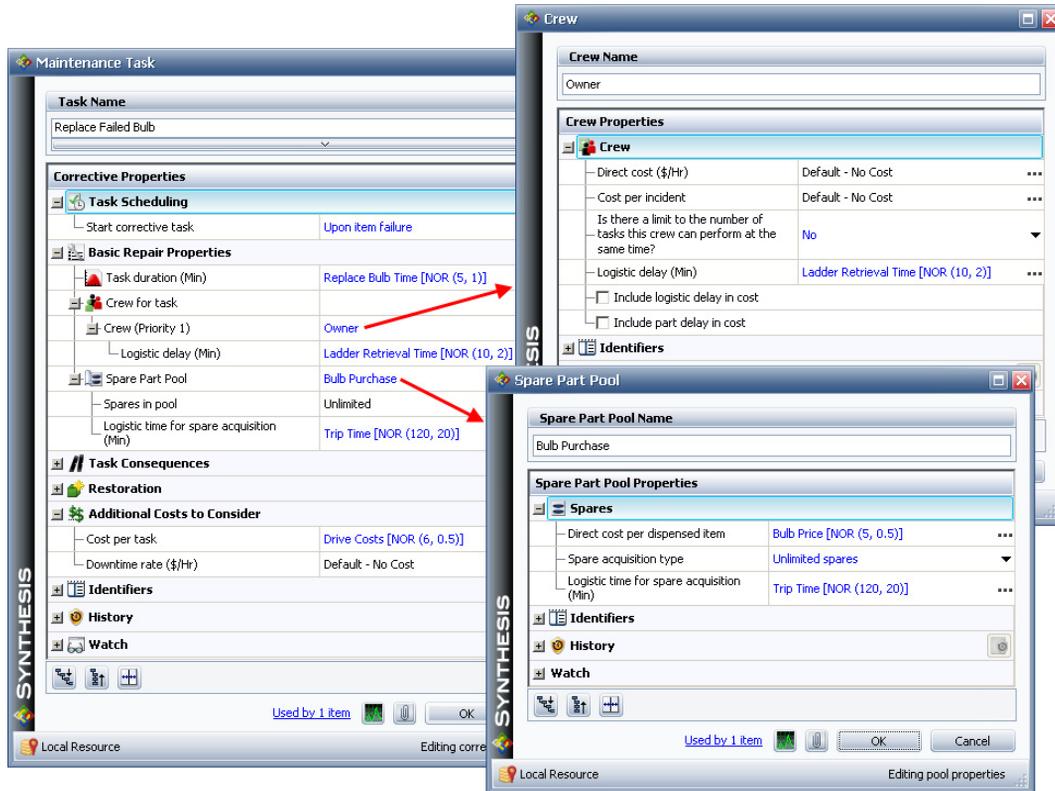
In this section, you will continue working with the “6. Chandelier - Maintenance Planning Part 2” project in the quick start repository, now using RCM++/RBI. *Note that this part of the analysis cannot be performed in Xfmea.*

Now that the FMRA has been updated, you return to RCM++/RBI to define the expected maintenance strategy and calculate the metrics of interest.

To see the corrective task for the Bulb (“Replace Failed Bulb” task), select the item in the FMRA hierarchy, click in the **Corrective Task** field and then click the **View/Edit** icon.



The task properties are as follows:



- The bulb will be replaced when it fails.
- It takes an average of 5 minutes with a standard deviation of 1 minute to actually replace the bulb. This is represented by the “Replace Bulb Time” model.
- The bulb will be replaced by the owner of the chandelier. To see the “Owner” crew properties, click in the **Crew (Priority 1)** field and then click the **View/Edit** icon.
 - It takes the owner about 10 minutes with a standard deviation of 2 minutes to get the ladder and set it up. This is represented by the “Ladder Retrieval Time” model.
- The owner does not keep spare bulbs on hand and will have to purchase one from a nearby home improvement store. To see the “Bulb Purchase” spare part pool properties, click in the **Spare Part Pool** field and then click the **View/Edit** icon.
 - The cost for the bulb is around \$5 with a standard deviation of \$0.50. This is represented by the “Bulb Price” model.

- The drive time, in-store time and return time for a trip total about 2 hours (120 minutes) with a standard deviation of 20 minutes, depending on the traffic and how busy the store is. This is represented by the “Trip Time” model.
- The car expenses (fuel, etc.) to get to the store are about \$6.00 with a standard deviation of \$0.50. These costs are represented by the “Drive Costs” model.

To see the corrective task for the Socket (“Replace Socket” task), select the item in the FMRA hierarchy, click in the **Corrective Task** field and then click the **View/Edit** icon. The task properties are as follows:

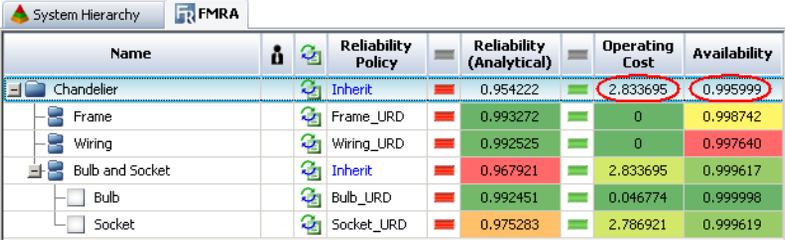
The screenshot displays the SYNTHESIS software interface. The main window is titled "Maintenance Task" and shows the "Replace Socket" task. The "Corrective Properties" section is expanded to show "Task Scheduling" and "Basic Repair Properties". The "Crew for task" is set to "Electrician" and the "Spare Part Pool" is set to "Socket Part". Two pop-up windows are overlaid on the main window. The "Crew" window shows the "Crew Name" as "Electrician" and lists properties such as "Direct cost (\$/Hr)" (Electrician Cost per Hour [90]), "Cost per incident" (Electrician Cost per Call [50]), and "Number of tasks" (1). The "Spare Part Pool" window shows the "Spare Part Pool Name" as "Socket Part" and lists properties such as "Direct cost per dispensed item" (Socket Price [50]), "Spare acquisition type" (Fixed probability of stockout), and "Fixed probability value" (0.5). Red arrows point from the "Crew" and "Spare Part Pool" fields in the task window to their respective pop-up windows.

- The socket will be replaced when it fails.
- It takes an average of 60 minutes (with a standard deviation of 20 minutes) to perform the socket replacement. This is represented by the “Replace Socket Time” model.

- If the socket fails, an electrician needs to be called. To see the “Electrician” crew properties, click in the **Crew (Priority 1)** field and then click the **View/Edit** icon.
 - On average, it takes 4 days with a standard deviation of 1 day for the electrician to arrive after the owner calls to schedule an appointment. This is represented by the “Electrician Scheduling Delay” model.
 - The electrician will charge \$90 per hour, represented by the “Electrician Cost per Hour” model, plus a fixed fee of \$50 per call, represented by the “Electrician Cost per Call” model.
- The electrician may or may not have a spare socket available. To see the “Socket Part” spare part pool properties, click in the **Spare Part Pool** field and then click the **View/Edit** icon.
 - There is a \$50 charge for the spare socket that will be used for the repair. This is represented by the “Socket Price” model.
 - There is also a 50% chance that the electrician will not have a spare socket available. This is set by choosing **Fixed probability of stockout** in the **Spare acquisition type** field and entering **0.5** in the **Fixed probability value** field.
 - If no socket is available, the electrician will drive to a nearby home improvement store (the same store where the owner buys spare bulbs) to purchase one. This is represented by the “Trip Time” model.

You want to know the system availability and associated costs, assuming a use of 5,000 hours. To show the Simulation Results Status, Operating Cost and Availability columns in the FMRA, right-click a column header and click **Customize Columns**.

You simulate the FMRA using an **Operation Time of 5,000 hours** (running 1,000 simulations, using a starting seed of 1 and a single thread).



Name	Reliability Policy	Reliability (Analytical)	Operating Cost	Availability
Chandelier	Inherit	0.954222	2.833695	0.995999
Frame	Frame_URD	0.993272	0	0.998742
Wiring	Wiring_URD	0.992525	0	0.997640
Bulb and Socket	Inherit	0.967921	2.833695	0.999617
Bulb	Bulb_URD	0.992451	0.046774	0.999998
Socket	Socket_URD	0.975283	2.786921	0.999619

You see that the projected system availability is approximately 99.60%, and the projected operating cost is \$2.83.

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