



## Reliability Engineering Using the GoldSim Reliability Module

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### Abstract

*Reliability engineering involves developing a model of an existing or proposed system in order to predict its in-service performance. Conventional techniques for reliability modeling often require assumptions and simplifications that may reduce the amount of information that can be obtained from a model, or may oversimplify its behavior. In addition, these techniques typically cannot address the overall performance of the system in terms of throughput, costs, or other measures.*

*GoldSim, in concert with the GoldSim Reliability Module, provides a suite of tools that allow a modeler to represent their particular system in as much detail as desired. Using this representation and GoldSim's dynamic Monte Carlo features, the modeler can obtain detailed information on the performance of the system and its components over time.*

*GoldSim is a powerful and flexible Windows-based computer program for carrying out probabilistic simulations of complex systems, and is used to support management and decision-making in business, engineering and science. The program is highly graphical, highly extensible, able to directly represent uncertainty, and allows you to create compelling presentations of your model. This paper provides a brief overview of GoldSim, with special emphasis on reliability simulation.*

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## Introduction

**What is Reliability Engineering?** Reliability engineering involves developing a statistical model of an existing or proposed system, which is used to predict its performance and optimize its design or its maintenance program. These models are frequently used to inform decisions about required levels of redundancy and to evaluate risk. They can also be used to compare design alternatives on the basis of metrics such as warranty and maintenance costs.

**Conventional Approaches to Reliability.** Most reliability approaches involve the assumption of a static model, where the system configuration never changes (other than due to the failure/repair of components), and where its properties don't change with time. This is a convenient assumption, as it allows the use of simple techniques, such as closed form mathematical equations or reliability block diagrams. Markov chains are another conventional reliability approach, and although they introduce an element of dynamism, the system itself (and its properties) cannot change with time. Because of the simplifying assumptions required to use these conventional techniques, they may be inappropriate for some systems.

*Closed-Form Equations* - These methods are heavily dependent on classical models (i.e., they have been primarily developed for use with standard failure distributions like the Poisson and Weibull). Even if failure data can be fitted to a standard distribution, it is difficult to model complex systems with closed form equations. For example, if a system has two Weibull failure modes, they cannot be algebraically combined into a single Weibull failure mode for use with the Weibull reliability equation.

*Reliability Block Diagrams* – Reliability block diagram models are static and do not account for the highly dynamic nature of many systems. A reliability block diagram model also assumes the system is in steady state, and unless correction factors are used, assumes that all of its components are independent.

*Markov Chains* – Markov chains enumerate a number of system “states” and the probabilities for transitioning between these states. However, the number of transition probabilities (and the computational effort) required to solve a Markov chain grows exponentially with the number of states. Because of this “state-space explosion” in many cases a system must be greatly simplified in order to use a Markov chain approach.

Of course, the conventional approaches are appropriate for many systems –particularly when employed by an experienced practitioner. However, in some cases, a more realistic reliability model may be required.

**The Alternative: Dynamic Monte Carlo Simulation Using GoldSim.** Dynamic simulation allows the analyst to develop a representation of the system whose reliability is to be determined, and then observe that system's performance over a specified period of time.

The primary advantages of dynamic Monte Carlo simulation:

- The system can evolve into any feasible state and its properties can change suddenly or gradually as the simulation progresses.
- The system can be affected by random processes, which may be either internal (e.g., failure modes) or external.
- If some system properties are uncertain, the significance of those uncertainties can be determined.

In Monte Carlo simulation, the model is run many times with random sampling of uncertain variables and events (each run is called a realization). These realizations are each considered equally likely<sup>1</sup>, and can be combined to provide not only a mean, but also confidence bounds and a range on the performance of the system. In addition to the statistical data these realizations provide, multiple realizations may also reveal failure modes and scenarios that may not be apparent, even to experienced reliability modelers.

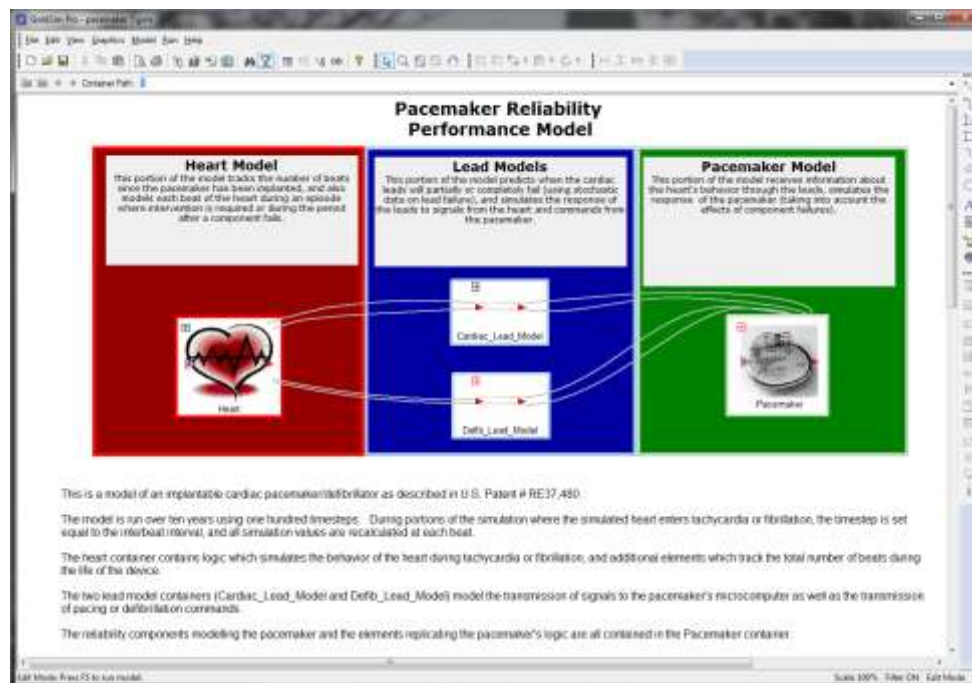
With GoldSim, you can:

- **Model Components that have Multiple Failure Modes:** GoldSim allows you to create multiple failure modes for components – each of which can either be defined by a distribution or occur when a specified condition arises. GoldSim also allows you to specify that specific modes are non-fatal, and allows you to query the status of any mode to determine the effects of these non-fatal modes on performance or throughput.
- **Model Complex Interdependencies:** In addition to providing a logic-tree mechanism to define relationships, GoldSim also allows you to model the more subtle effects of failure on other portions of the system. For example, in GoldSim, you can easily model a situation where the failure of one component causes another component to wear more quickly.
- **Model Resource Utilization:** Stocks of Resources, such as spare parts, consumables and employees, can be modeled in GoldSim and required to start, operate or repair components of the reliability system.
- **Model the External Environment:** Reliability elements in GoldSim are fully compatible with all GoldSim elements. This means that the environment in which the reliability system operates can also be modeled and can affect and interact with the system.
- **Understand Throughput:** For complex processing systems (factories, or plants of different types) predicting and optimizing throughput is very difficult, and GoldSim provides an unequalled way to create throughput-optimized designs.
- **Design Optimal Maintenance Programs:** GoldSim offers the ability to simulate and optimize maintenance activities taking into account spares inventories and personnel levels.

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<sup>1</sup> GoldSim also gives the user an option to select importance sampling in order to generate more samples of low-probability, high-impact realizations.

## Overview of the GoldSim Simulation Framework



GoldSim is a powerful and flexible platform for visualizing and numerically simulating nearly any kind of system. The GoldSim simulation environment is highly graphical and completely object-oriented. That is, you create, document, and present models by creating and manipulating graphical objects (referred to as elements) representing data and relationships between the data. Based on how the various objects in your model are related, GoldSim automatically indicates their influences and interdependencies by visually connecting them in an appropriate manner.

Beyond its reliability simulation capabilities, GoldSim also has a number of features that make it unique amongst dynamic Monte Carlo simulators:

- **GoldSim is user-friendly and highly graphical**, such that you can literally draw (and subsequently present) a picture (an influence diagram) of your system in an intuitive way without having to learn any arcane symbols or notation.
- **GoldSim is extremely flexible, allowing it to be applied to nearly any kind of system.** The software allows you to build a model in a hierarchical, modular manner, such that the model can readily evolve as more knowledge regarding the system is obtained. Hence, a GoldSim model can be very simple or extremely complex.
- **Uncertainty in processes, parameters and future events can be explicitly represented.** Uncertainty in processes and parameters can be represented by specifying model inputs as probability distributions. The impact of uncertain events (e.g., earthquakes, floods, sabotage) can also be directly represented by specifying the occurrence rates and consequences of such "disruptive events".
- **GoldSim is highly extensible.** You can dynamically link external programs or spreadsheets directly into your GoldSim model. In addition, GoldSim was specifically designed to support the addition of customized modules (program extensions) to address specialized applications.

- **GoldSim allows you to create compelling presentations of your model.** A model which cannot be easily explained is a model that will not be used or believed. GoldSim’s hierarchical design allows components of the model to be placed in the most intuitive location. For example, if you were building a model of a car, the engine and transmission elements would be placed inside the car element. In addition to permitting the intuitive construction of models, GoldSim was specifically designed to allow you to effectively document, explain and present your model. You can add graphics, explanatory text, notes and hyperlinks to your model, and organize it in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audiences.

## GoldSim’s Reliability Module

The GoldSim Reliability Module is a program extension to the GoldSim simulation software that adds two powerful element types specifically designed to allow you to model the reliability of complex engineered systems efficiently.

These elements are:



Function1

**The Function Element.** The Function Element is used to represent processes or services that are carried out over a period of time: an air-conditioning system, a battery, a back-up generator, and so on. The Function element provides outputs that inform other elements in the model whether or not the component is functioning correctly. This allows for dependency relationships to be easily defined, for example a radio component might require a power-supply component to be operating.



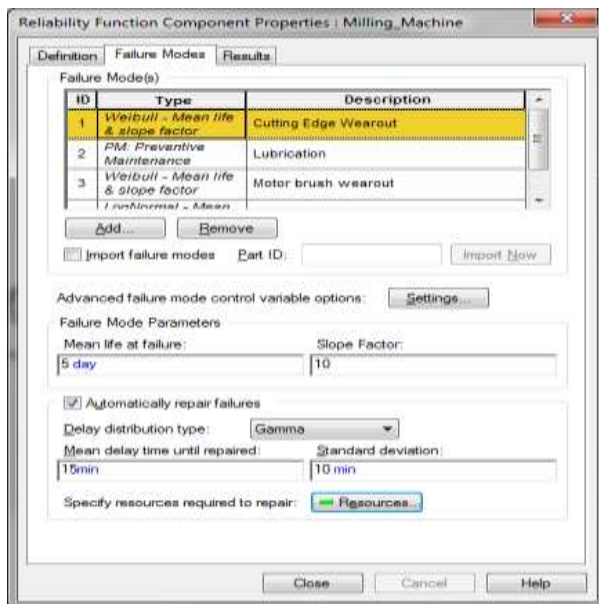
Action1

The **Action element** represents activities that are carried out instantaneously: a door latches closed, a switch opens or closes, an engine starts, a message is delivered, and so on. The Action component waits for a triggering input to tell it to carry out its action.

When a model is first created each major component might be represented using a single Function or Action element. As more information becomes available, or if it is determined that a component needs to be modeled in more detail, it is possible to turn any component into a system that contains one or more “child” elements.

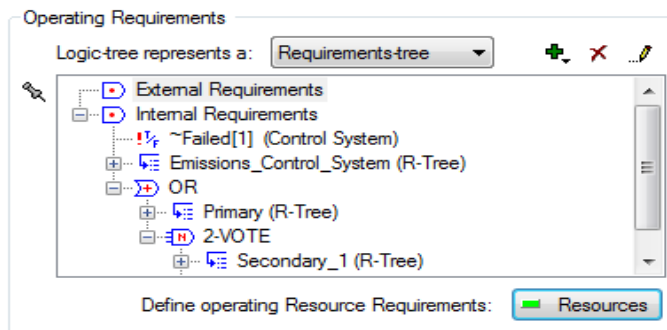
Turning an element into a system allows an unlimited number of reliability elements (including other reliability elements modeled as systems) to be placed inside the element. This process of successively embedding more detailed subsystem models can be carried out to any depth, and these “child” elements can interact with each other and with the “parent” reliability element to model complex interactions in as much detail as is necessary.

The Function and Action elements have many parts in common. Common components include:



**Failure Modes.** You can specify up to 10 individual failure modes for each action or function element. GoldSim offers 14 different types of failure, and each failure mode can use one of GoldSim’s built-in control variables (time, number of actions), or it can be linked to a user-defined control variable.

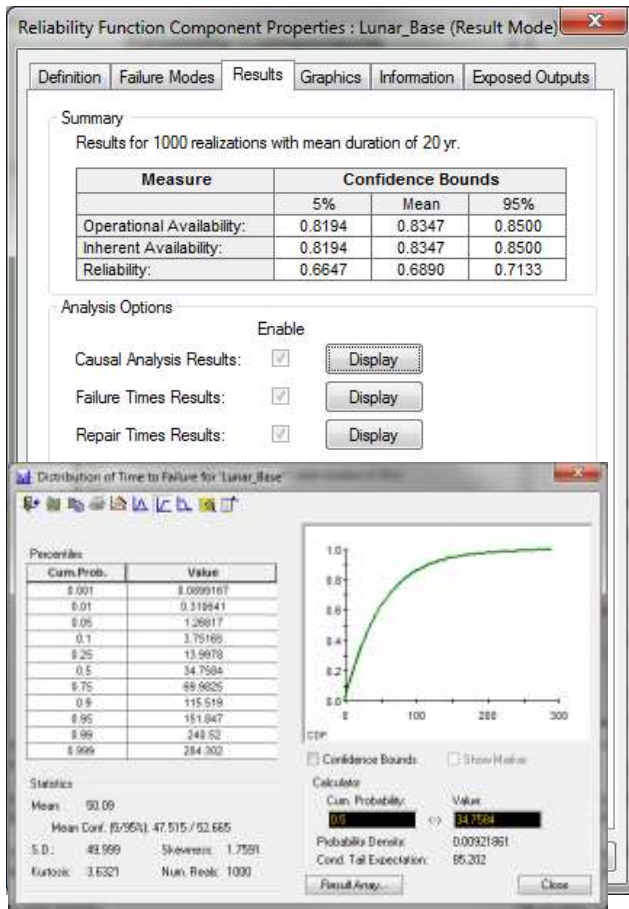
**Maintenance Support.** GoldSim allows you to specify automatic repair parameters for any failure mode, and also allows you to set up preventive maintenance events which can either selectively repair failure modes back to a new, or partially degraded state, or can replace the component and any of its subcomponents. Resources such as spare parts and technicians can also be required to repair a failure mode.



**Logic-Tree.** Both elements allow you to create a requirements tree or fault tree outlining the internal (child element) and external (peer element) conditions under which the element can successfully operate. These logic-trees allow you to query the status of other reliability elements or specify conditions referring to any GoldSim element or property.

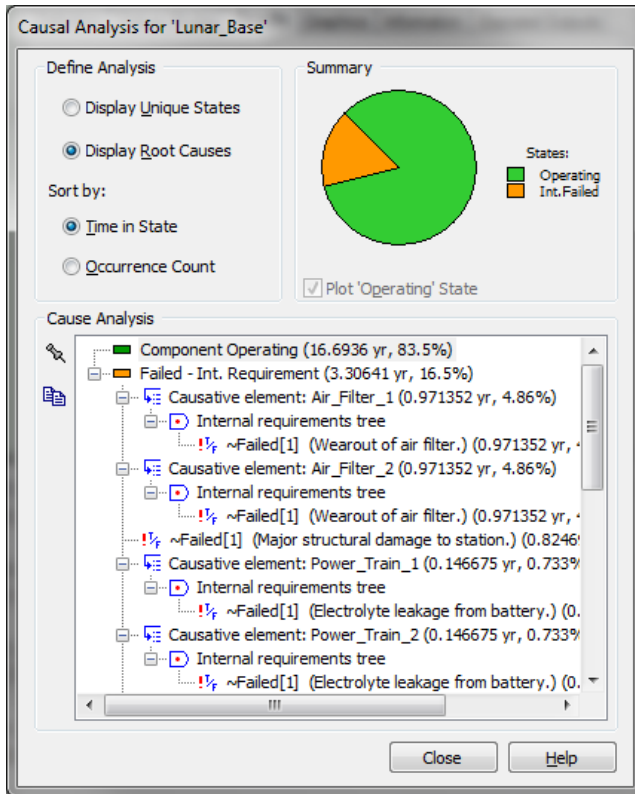


**Resources.** You can simulate competition for resources such as spare parts, equipment or technicians that are required in order to start, operate or repair components of your system.

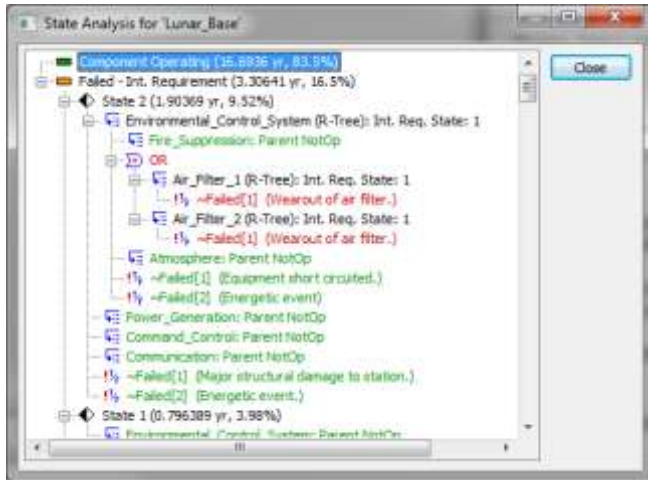


**Results Analysis.** GoldSim provides a number of reliability analysis tools that become available at the end of a simulation. These tools are accessible via the Results tab in any reliability element.

The summary section provides reliability and availability statistics over the duration of the simulation. However, because a dynamic Monte Carlo simulation was run, a wealth of additional data, such as statistics on failure and repair times, are available.



One of the most powerful types of result processing available with GoldSim's reliability module is **Causal Analysis**. Because GoldSim records all of the unique conditions which result in failure of each individual element during a simulation, it can provide analyses that identify failure scenarios and failure root causes for each reliability element. The screenshot to the left shows how a root-cause analysis can identify the underlying causes of failures of a complex system.

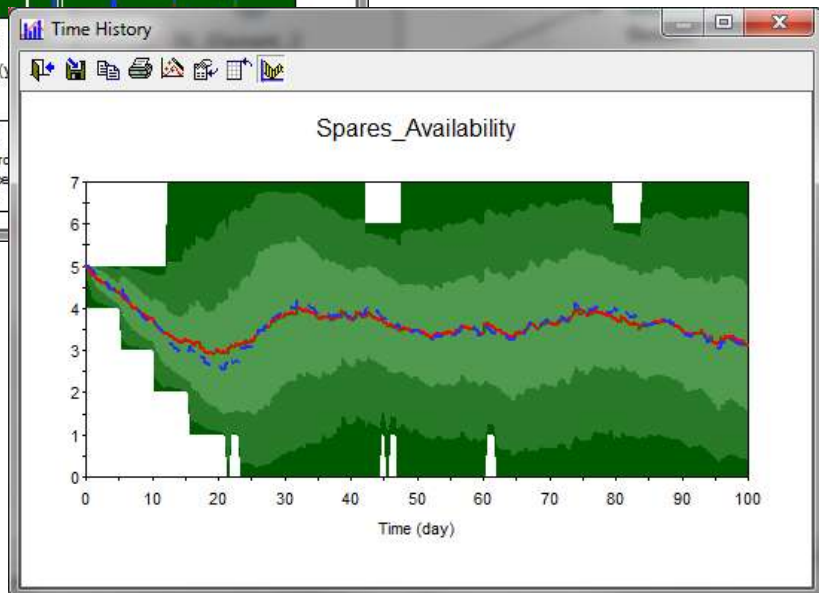
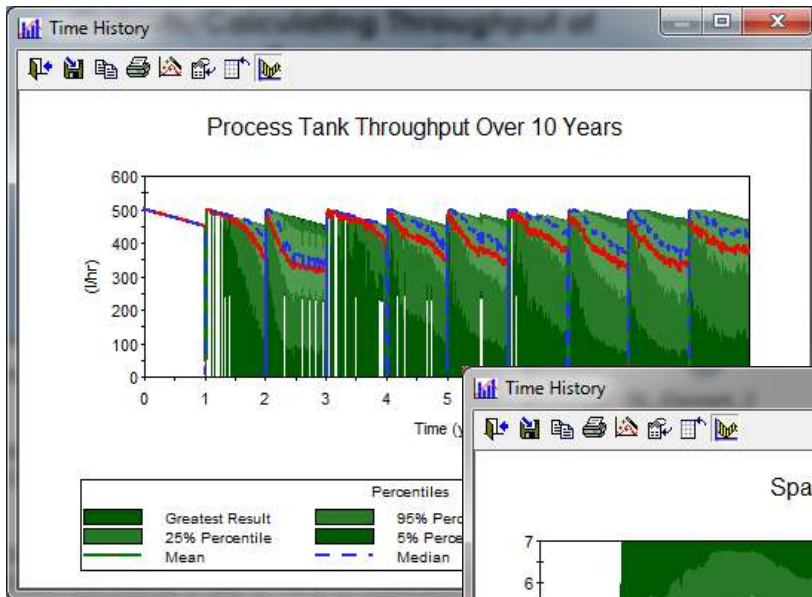


A related analysis shows the different failure scenarios for a system, where each scenario corresponds to a specific state of the system's components. Each state is presented as a logic-tree, with each false node (for requirements-trees) or true node (for fault-trees) shown highlighted in red.

In addition to these reliability specific results, other GoldSim elements and features can be used to provide a wealth of insight into the operation of the system being modeled.

For example, the plot at left below shows the throughput rate (with confidence bounds) of a process tank for 10 years following its entry into service.

The graph at right below shows a plot of spare parts levels (with confidence bounds) from another reliability model with three identical components.



## Summary

Dynamic, probabilistic simulation using GoldSim can provide valuable insights into the performance of complex engineered systems that are difficult to model using conventional reliability approaches. Reliability engineers can incorporate all of their knowledge regarding the system into a computer model that allows them to:

- Predict the performance of the system
- See confidence bounds on the predictions
- Identify critical components
- Identify key failure modes

These technical results can be used by managers to:

- Focus design and/or testing resources where they are most likely to have a positive impact,
- Contrast design alternatives on the basis of warranty or maintenance costs, and
- Ensure that the system will meet customer and regulatory requirements for reliability.

In this way, the GoldSim approach provides a method by which the system's performance can be evaluated without having to experiment on a real system, which may be prohibitively costly, time-consuming, or simply impractical.

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## **About the GoldSim Technology Group**

The GoldSim Technology Group is dedicated to delivering software and services to help people understand complex systems and make better decisions. Our flagship GoldSim software package is based on technology developed over the past seventeen years, and our clients include the U.S. Department of Energy, the U.S. Nuclear Regulatory Commission, NASA, Caterpillar, General Dynamics Land Systems, Alcan Engineering, and the UK Ministry of Defence.

The GoldSim software package is a generalized simulator suitable for modeling any type of real-world system and has been used to solve problems related to strategic planning, portfolio analysis, risk assessment, program planning, supply chain management, environmental systems, and engineered systems.

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