# Reliability Engineering Principles: Optimizing System Design

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## Introduction

In everyday life, we are faced with making all kinds of decisions in both our personal and professional lives. Decision analysis involves the use of a rational process for selecting the best of several alternatives. The solution to any decision-making problem requires identifying three main components:

- What are the decision alternatives?
  Examples: Should I select vendor X or vendor Y? Should I keep an additional spare component or not?
- Under what restrictions or constraints is the decision made?
  Examples: The budget for procuring new equipment cannot exceed $10,000. The average annual downtime of the system should not exceed 48 hours.
- What is an appropriate objective criterion for evaluating the alternatives?
  Examples: Should the goal be to maximize overall profit, maximize system availability, or minimize overall cost?

Generally, the alternatives of the decision problem take the form of unknown variables. The variables are then used to construct the restrictions and the objective criterion in appropriate mathematical functions. The result is a mathematical model relating the variables, restrictions, and objective criterion. The solution of the model yields the values of the decision variables that optimize, either maximize or minimize, the value of the objective criterion while satisfying all the restrictions. The resulting solution is referred to as the optimum feasible solution or simply the optimal solution. A typical mathematical model for optimal decision-making is organized as follows:

Maximize or minimize (Objective function)
subject to (Constraints)

## Designing an Optimal System

System design is one of the important applications of optimal decision-making problems. The fundamental goal of a system design is to build the system such that it performs its functions successfully. The inability of the system to perform its functions is called a system failure. Several factors related to system design as well as external events influence the system functionality. In most cases, the effects of these factors are random, which means that they cannot be determined precisely but can only be explained through probability distributions. Therefore, the failure event or the time to system failure is a random variable.

The engineering discipline that deals with the successful and unsuccessful or failure operations of systems is known as reliability engineering. Reliability is a critical system characteristic and is defined as the “probability that the system performs its intended or specified functions successfully over a specified period of time under the specified environment.” One of the goals of reliability engineering is to carefully design and analyze a system design to build the highest reliability into the system within the limits of economical and physical constraints. Some important principles for enhancing system reliability follow.

- Keep the system as simple as possible while still meeting all performance requirements. This can be achieved by minimizing the number of components in series and their interactions.
- Increase the reliability of the components in the system. This can be achieved by reducing the variations in the components' strength and applied load through better quality control and monitoring of operational environment, increasing the strength of the components by substituting better materials, and reducing the applied load. Alternatively, increasing component reliability can be achieved by using large safety factors or management programs for product improvement.
- Use burn-in procedures for components that have high infant mortality to eliminate early failures in the field.
- Use redundancy, or spares, for less reliable components. This can be achieved by adding spares in the parallel or standby redundancy.
- Develop a fault-tolerant design such that the system can continue its functions even in the presence of some failures. This can be achieved using sparing redundancy, fault-masking, and failover capabilities.

Additionally, if the system or its components are repairable, the availability of the system should be considered as a system performance index. Availability of the system is “the probability that the system is operational at a specified time.” In a long run, the system availability estimate reaches an asymptotic value called steady-state availability. In most cases, reliability engineers focus their attention on improving the steady-state availability of the system, which can be accomplished by reducing the downtime. Some important principles for enhancing the reliability of a repairable system follow.

- Use design methods that increase the reliability of the system.
- Decrease the downtime by reducing delays in performing repairs. This can achieved by keeping additional spares onsite, providing better training for repair personnel, using better diagnosis procedures, and increasing the number of repair personnel.
- Perform preventive maintenance such that components are replaced by new ones whenever they fail, or at some regular time intervals or age, whichever comes first.
- Perform condition-based maintenance such that downtime related to either preventive or corrective maintenance is minimal.
- Use better arrangements of exchangeable components.

Implementation of the above principles to improve system performance such as reliability or availability typically consumes some resources, which may be limited. Resource limitations may include available budget, space to keep components, and weight limitations. In such cases, the objective should be obtaining the maximum system performance within the utilization of the available resources. However, in some cases, achieving high performance may not lead to the maximum overall profit or minimum overall cost. In such cases, the system design should be optimized to achieve the most cost-effective solution that strikes a balance between the system, the cost of system failure, and the cost of efforts for reducing system failures.

## Building Cost-Effective Systems

In the majority of applications, the objective of system design is to minimize the overall cost associated with the system. The total cost is the sum of several cost factors, such as:

- System failure costs, which includes damage and inconvenience costs
- Downtime costs associated with loss of production
- Component and spare costs
- Maintenance costs, which includes repair, replacement, and inspection costs
- Maintenance personnel costs, which includes call-up costs and hourly rates
- Warranty costs
- Storage costs
- Transportation costs
- Miscellaneous costs, which includes replacing accessories

The actual formulas and cost factors vary with the applications.

## Defining System Design Objectives

Depending on the situation, the objective of optimal system design can be any one of the following.

- Maximize system performance.
  There are a number of measures that indicate the performance of a system. For non-repairable systems, reliability is an important performance measure. For repairable systems, availability or total uptime is important. When the system has several levels of performance, such as in a multi-state system, the average capacity or throughput is important.
- Minimize the losses associated with unwanted system behaviors.
  The system can be designed in such a way that the losses associated with downtime can be minimized. Losses can therefore be minimized by reducing unreliability, unavailability, downtime, or the number of failures.
- Maximize the overall profit or minimize the overall cost associated with the system.

In general, the optimal design corresponding to the maximum system performance may not exactly coincide with the optimal design that maximizes system profit. Similarly, the optimal design corresponding to the minimum occurrences of unwanted behaviors may not exactly coincide with the optimal design that minimizes overall cost. In such cases, the objective should be to minimize the overall cost associated with the system design that meets both system performance requirements and all resource consumption restrictions.

One of the major challenges to solving the optimal system design problem is computing the objective function. Unless a system is simple or well structured, obtaining a closed-form mathematical expression for the objective function is extremely difficult. When there are dependencies such as common-spares, exchangeable components, time-varying failure and repair rates, imperfect maintenance actions, and so on, obtaining a closed-form expression is virtually impossible. In such cases, the objective function can be calculated using either numerical methods or simulation. Thus, the methods for finding the optimal solutions should not depend on the form of the objective function.

## Decision Variables

Decision variables are the values that must be found such that the specified objective is minimized or maximized. Decision variables include:

- Type of system configuration

- Types of components or spares
- Number of spares in a specific application or subsystem
- Number of repair personnel
- Preventive maintenance intervals
- Inspection intervals
- Replenishment intervals

The type of component is applicable if there are several alternative components for the same application with varied costs, weights, volumes, and failure rates or reliabilities. When the decision variables include the number of spares, the problem is called a spares optimization problem or redundancy allocation problem.

## Identifying System Constraints

The optimal solution should be obtained within the resource restrictions. These restrictions are also called the constraints of the optimization problem. Constraints include:

- Desired reliability
- Desired availability
- Desired MTTF or MTBF
- Allowed downtime
- Allowed unavailability
- Allowed budget for spares and/or repair resources
- Allowed weight
- Available space or volume

Additional information about this topic can be found in the "Optimal System Design" chapter authored by Dr. Suprasad Amari of Relex Software Corporation in the *Springer Handbook of Engineering Statistics*, edited by Dr. Hoang Pham.

## Conclusion

Optimal system design involves identifying objective functions, which are also called goals, as well as decision variables and constraints. The Relex System Optimization and Simulation (OpSim) module supports various goals, decision variables, and constraints. This comprehensive system modeling tool provides the power necessary to analyze complex, multi-dimensional system configurations using sophisticated techniques. By taking into account maintenance activities, spare parts, and repair resources, Relex OpSim lets you take standard reliability block diagrams (RBDs) to the next level. For additional information about how Relex OpSim provides the power necessary to model true-to-life, complex scenarios, visit www.relex.com/products/opsim.asp.