Applied Risk Analysis of Complex Systems

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Abstract

Systems are typically assessed on variety of metrics, reliability being only one. Because performance metrics are often highly interrelated, system analyses need to account for all metrics simultaneously. Systems are often complex, yet decision makers require quick analysis response and flexibility in system specification. This paper describes a system modeling strategy that has successfully met these needs.

1. Introduction

In her plenary lecture, Sallie Keller-McNulty made the important point that reliability is just one aspect of system performance. Systems are also assessed on a variety of metrics such as quality, cost, schedule, and safety. Decision makers are generally concerned with the entire array of system metrics and the associated uncertainties that lead to risk. Further, systems are often complex with changes in one component impacting all performance metrics. In order to be of real value to decision makers, it is important that system analyses be performed on a timely basis, are able to provide critical information, and be able to accommodate system modifications and analyze scenarios easy. This paper describes a method of system modeling that has successfully provided these capabilities.

2. A General System Representation

Systems may be represented in many forms. Following is a description of one particular representation that has been successfully applied at Los Alamos National Laboratory (LANL) to perform risk analyses of complex systems. The model has a heavy foundation in economic theory (Nicholson 1998, Varian 1992). The model is quite simple, yet can be applied in a wide variety of situations.

The essence of the model is depicted in Figure 1. The two fundamental objects in the model are activities and factors. An activity is just what the name implies. For the moment, think of factors as physical resources such as materials. There are two types of relationships in the model. One is a temporal relationship that specifies time dependencies between activities, represented in Figure 1 by the solid line connecting Activity 1 and Activity 2. A simple example is that one activity cannot begin until another is complete. The other type of relationship is factor utilization, represented in Figure 1 by the dotted lines connecting the Factor to Activities 1 and 2. The fundamental idea is that activities can produce or consume factors. The model is quantified through the variables describing the properties of the activities, the properties of the factors, and the relationships. Uncertainty is captured in the model by making variables random where appropriate.

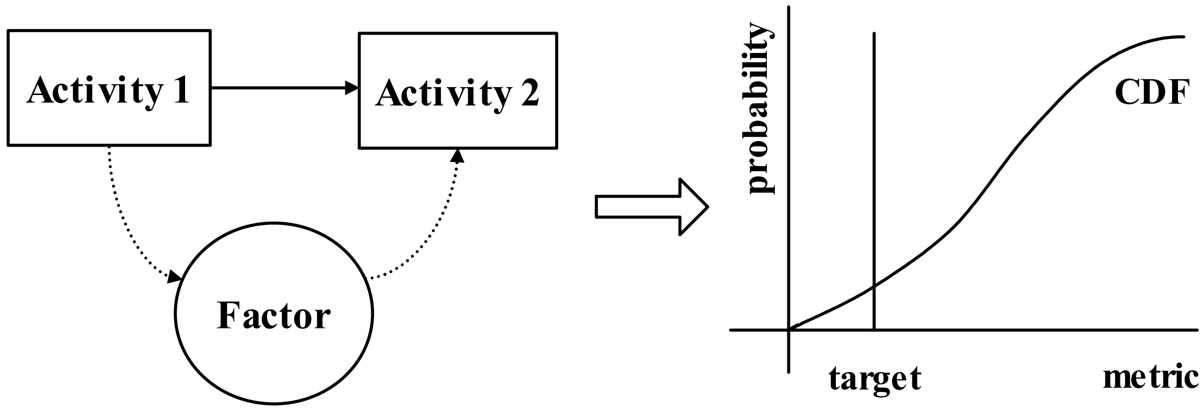

Figure 1. General System Representation

Closed form expressions for metrics of system performance can sometimes be found for models of the form illustrated in Figure 1. Monte Carlo simulation is often required for complex systems. In either case, a common output of the model analysis is the estimated CDF of the metric. When compared to targeted values, the probability that the system will not perform as intended can be computed. This probability is a critical component of system risk analyses.

The model illustrated in Figure 1 is quite simple. One advantage of simplicity is that the tools used to construct and analyze the model are correspondingly simple. Models for systems that fit the structure illustrated in Figure 1 can be constructed and analyzed quickly and accurately. The penalty for simplicity is often limited applicability. The key to making this model widely applicable is to generalize the concept of a factor. Factors can be physical resources such as people, materials, equipment, and facilities. However, factors need not be so concrete. For example, in this modeling framework reliability would be a factor produced by a development activity, and a reliability estimate would be a factor produced by a testing activity. Further, factors need not be desirable. Many activities create real or potential hazards as an unintended side product, and the magnitude of these hazards are of real interest to decision makers. Hazards are also represented in the model as a factor produced by an activity. By allowing the definition of a factor to be quite general, the model illustrated in Figure 1 can accommodate a surprisingly wide range of systems.

3. An Example

One mission of LANL is the production of detonators. A very simplified description of the process follows. A development lot is first produced and evaluated by test-fire and other inspections. The results of these evaluations provide information for reliability estimates, and the test firing may create hazards for workers. After the test lot is produced and evaluated, the final lot is produced. All of these activities require funding. The activities in this example are test production, test firing, inspection, and final production. The factors are budget, test detonators, final detonators, hazards, and reliability. A model of this system is illustrated in Figure 2. Even though the described system is a gross simplification of reality, the system is already quite complex. A change in the number of test fires impacts not only reliability, but also all the other metrics of interest to decision makers: cost, hazards and schedule. Construction of the model is greatly simplified using the structure described in Section 2. While the factors in the model are very different in reality, in the model they are treated as the same fundamental object, but with different properties.

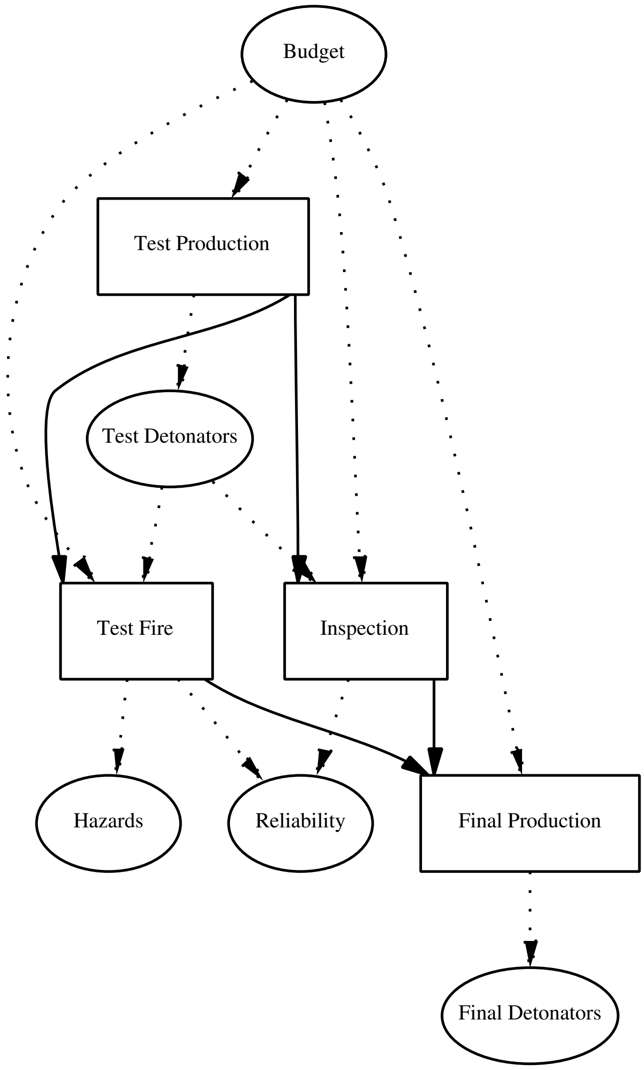

Figure 2. Representation of Detonator Production System

References

Nicholson, W. (1998). *Microeconomic Theory*. Fort Worth: Dryden.
Varian, H. (1992). *Microeconomic Analysis*. New York: W. W. Norton.