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Modeling uncertain activity duration by fuzzy number and discrete-event simulation

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Abstract

This paper introduces how to incorporate fuzzy set theory and a fuzzy ranking measure with discrete-event simulation in order to model uncertain activity duration in simulating a real-world system, especially when insufficient or no sample data are available. Fuzzy numbers are used to describe uncertain activity durations, reflecting vagueness, imprecision and subjectivity in the estimation of them. A fuzzy ranking measure is merged with an activity scanning simulation algorithm for performing fuzzy simulation time advancement and event selection for simulation experimentation. The uses of the fuzzy activity duration and the probability distribution-modeled duration are compared through a series of simulation experiments. It is observed that the fuzzy simulation outputs are arrived at through only one cycle of fuzzy discrete-event simulation, still they contain all the statistical information that are produced through multiple cycles of simulation experiments when the probability distribution approach is adopted.

Keywords: Discrete-event simulation; Fuzzy sets theory; Fuzzy number; Fuzzy ranking; Uncertainty activity duration

1. Introduction

Discrete-event simulation is used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid analysis and design of management policies for the construction process. Developing a simulation model, namely modeling, is key to discrete-event simulation. Input modeling for defining the information or parameters of a system being modeled strictly determines the quality of the simulation results (Maio et al., 2000). Inappropriate input leads to misleading simulation outputs, and therefore error-prone or sub-optimal planning and management decisions (Stephen, 1999). Difficulties in input modeling, including the lack of confidence in input information, have limited the use of discrete-event simulation as a practical tool for construction (Fente et al., 2000).

Generally, modeling activity duration is achieved through importing observed data or probability distributions derived from sample data.

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However, the use of real data in simulation is time-consuming taken to collect large amounts of field data for reproduction of the real operation system (Law and Kelton, 1991). The definition of probability distributions is considered to be intractable; theoretically too complicated and computationally too expensive (Gaul, 1981; Klein, 1986). The issues on how to define probability distributions for activity duration through sample data in the construction field have been widely studied (AbouRizk and Halpin, 1992; Fente et al., 2000; Maio et al., 2000; Wilson et al., 1982; Klein and Baris, 1990; Touran, 1997; Weiler, 1965). It is concluded that some real-life characteristics may be left out if a small number of data are collected; the goodness-of-fit between data and distributions may be weak even when a large number of data are available. Hence subjectivities in selecting distributions and estimating related parameters are unavoidable (Nasution, 1999; Fente et al., 2000; Lu, 2002). The most difficult aspect of duration-input modeling is gathering data of sufficient quality, quantity, and variety (Stephen, 1998). However, in some contexts it may be impossible or infeasible to collect data due to, for example, the uniqueness of construction activities and sometimes labor agreements that preclude collection of performance data, while for other cases there may be insufficient time or personnel to carry out extensive data collection.

In respect to such situations, the estimation of activity durations by experienced engineers or experts is often adopted. Therefore, more often than not, there is subjectivity, vagueness or imprecision in the estimated activity duration. Further, there are some activity-duration uncertainties characterizing the real-world construction process due to factors such as changing weather conditions, equipment properties, labor efficiency, supply conditions of materials and coordination problems among stakeholders, etc. Fuzzy set theory (Zadeh, 1965; Bellman and Zadeh, 1970) provides a good mathematical methodology to describe and handle the problem of vague and imprecise activity durations.

Fuzzy set theory has been applied to network-based planning techniques by some scholars such as Duobis and Prade (1988), Nasution (1999), Chanas and Kamburowski (1981), and Lootsma (1989). In addition, fuzzy set theory has been applied to modeling uncertain production environments through continuous simulation (Dohnal, 1983; Fishwick, 1991; Negi and Les, 1992; Petrovic et al., 1998; Southall and Wyatt, 1988). Fuzzy logical control has been integrated with discrete-event simulation to model flexible activity start conditions and fuzzy-ruled computation of activity duration varying with the amounts of involved materials (Zhang et al., 2003). Examples of modeling fuzzily estimated activity durations through combining the fuzzy set theory with the discrete-event simulation are scarce, especially for the construction-oriented simulation.

The combination of fuzzy set theory with discrete-event simulation to handle subjectivity, vagueness or imprecision in estimating activity duration so as to solve some problems in using probability distributions is presented in this paper. In addition, a fuzzy ranking measure and its application to the control of fuzzy-time advancement and event selection for the simulation experiment of discrete-event simulation are described. Illustrations on the fuzzy discrete-event simulation and an example that compares the fuzzy discrete-event simulation with the traditional probability distribution-based simulation are also provided.

2. Description of activity duration with triangular or trapezoidal fuzzy number

Although many types of fuzzy sets (Zadeh, 1965) have been used to describe uncertainties, triangular and trapezoidal fuzzy sets (Fig. 1) are very often used in the applications (e.g., fuzzy controllers and managerial decision-making) because the parameters defining them can be easily specified in linguistic terms (Yoon, 1996; Bojadziev and Bojadziev, 1997). In addition, only triangular or trapezoidal fuzzy sets suit the fuzzy ranking measure (Tran and Duzkstein, 2002) that will be introduced in Section 4. Therefore, triangular or trapezoidal fuzzy sets are applied to describe uncertain activity duration in the research. Fuzzy numbers are the fuzzy sets that are normalized and convex (Bojadziev and Bojadziev, 1997). Accord-