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Estimating the duration of stochastic workflow for product development process

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Abstract

The purpose of this study is to consider a stochastic workflow in the product development process with both random activity durations and predefined resource constraint and to develop the method of estimating the completion time in the product development process. We first present a stochastic workflow considering resource constraints and then develop a method to estimate the parameters of completion time in the product development process using a Markovian model. We present a practical case study to show that our method can be effectively used in practice.

Keywords: Workflow; Lead time; Stochastic process; Resource constraint

1. Introduction

A workflow has been traditionally defined in office terms—moving the paper, processing the order, or issuing the invoice. The workflow management coalition defines the workflow as the automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules (WfMC, 1999). A workflow consists of a set of activities, while an activity is a description of a piece of work that forms one logical step within a process. An activity requires human and/or machine resources to support process execution. It can be manually executed, or it can be automated.

Nowadays, the workflow receives much attention for its capability to support today's complex business processes, such as product development process especially. Product development process is the process of transforming customer needs into an economically viable product that satisfies them. There are many research spans on product development process ranging from engineering to management, and recent research on product development process has focused on the approaches for reducing lead time, cutting costs, and improving product quality. In addition, there has been also an important research issue—estimating the overall duration of a project or product development process.

In estimating the duration of a project or product development process, an activity-on-arc (AoA)

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directed acyclic graph method, which has one start node s and one finish node t, has been widely used. This type of graph is often called a stochastic activity network or program evaluation and review technique (PERT) network (Malcolm et al., 1959). In a stochastic activity network, durations of all activities are positive random variables with known probability distribution. The completion time of a project or product development process is also a random variable whose realization can be determined, but whose exact distribution function is very difficult to calculate for most stochastic activity networks. The difficulty in obtaining the distribution function is that there are a large number of paths in stochastic activity networks and interdependencies among them. In practice PERT or the product development process is usually carried out with limited resources. However, most researches ignore the resource constraints, and the need for proper resource-constrained stochastic activity network problem is now being needed. To the best of our knowledge, few of the existing techniques clearly consider this subject from structural viewpoints. The main research directions to explore the distribution function of a project or product development process are discussed next.

1.1. Related works

The Followings are the main approaches to estimating the completion time of the stochastic activity networks with or without considering the resource constraints.

Exact analysis: Martin (1965) has provided a systematic way of converting any directed, acyclic network to series-parallel form and presented the efficient computation method for the density function of the completion time from start to terminal node, under the restriction that the arc (or activity) density functions are polynomials. Hartley and Wortham (1966) consider block series-parallel networks of mini-networks. They allow the mini-networks to be single arcs or wheatstone bridges. They develop formula to replace a wheatstone bridge by a single arc with appropriate distribution. Ringer (1969) extends the algorithm developed by Hartley and Wortham by allowing double wheatstone bridge as mini-networks. Fisher et al. (1985) construct what they call "order-of-precedence"(OP) diagrams and take a conditional approach to compute the completion time of a project, but computational size of his work is enormous even for small networks. Hagstrom (1990) considers a recursive conditioning procedure which applies to graphs with discrete distributions. However, most of their results are limited in that they make quite restrictive assumptions.

Approximating and bounding approaches: As mentioned before, computing the distribution of completion time of a project or product development process is a hard problem. Hence several researchers have developed bounds and approximations for distribution and/or moments of project completion time. Dodin (1985a, b) derives a bound for project completion time with assumption of independent random variables for activities. Robillard and Trahan (1977) derive a lower bound using Laplace transformations, assuming that activity times are independent. Also, Kleindorfer (1971) provides upper and lower bounds for project completion time where discrete random variables are considered for activities. Kamburowski (1985) obtains upper and lower bounds for mean and lower bounds for variances for project completion time. Fulkerson (1962), Elmaghraby (1967), and Robillard and Trahan (1976) derive bounds for mean of project completion time for some cases. Dodin (1985a, b) presents an analytical procedure to approximate the distribution function of the longest path in stochastic networks. Dodin and Sirvanci (1990) proposes the extreme value distribution as an approximation of the project completion time and also claim that the distribution of project completion time varies from a normal to an extreme value distribution depending on factors such as the size of the network, the dependence between paths and the number of dominating paths.

Simulation methods: These methods have been discussed in the literature by Van Slyke (1963), Burt and Garman (1971), and Sigal et al. (1979). Van Slyke (1963) develops the idea of using crude Monte Carlo simulation as a tool for estimating the distribution of a PERT network's completion time. Burt and Garman (1971) introduce a conditional Monte Carlo method which depends on the number of unique arcs in a given network. A unique arc is one which lies on exactly one network path. Sigal et al. (1979) present Monte Carlo methods using a new network concept, uniformly directed cutsets (UDCs) for analyzing directed, acyclic networks with probabilistic arc durations.

RCPSP and TOC: Considering a stochastic activity network together with resource constraints, the stochastic RCPSP (resource-constrained project