European Journal of Operational Research 247 (2015) 879–894

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Decision Support

Resource allocation in multi-class dynamic PERT networks with finite capacity

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ARTICLE INFO

Article history:
Received 4 May 2013
Accepted 15 June 2015
Available online 24 June 2015

Keywords:
Project management
Markov processes
Multiple objective programming
Simulated annealing

ABSTRACT

In this paper, the resource allocation problem in multi-class dynamic PERT networks with finite capacity of concurrent projects (COnstant Number of Projects In Process (CONPIP)) is studied. The dynamic PERT network is modeled as a queuing network, where new projects from different classes (types) are generated according to independent Poisson processes with different rates over the time horizon. Each activity of a project is performed at a devoted service station with one server located in a node of the network, whereas activity durations for different classes in each service station are independent and exponentially distributed random variables with different service rates. Indeed, the projects from different classes may be different in their precedence networks and also the durations of the activities. For modeling the multi-class dynamic PERT networks with CONPIP, we first consider every class separately and convert the queueing network of every class into a proper stochastic network. Then, by constructing a proper finite-state continuous-time Markov model, a system of differential equations is created to compute the project completion time distribution for any particular project. The problem is formulated as a multi-objective model with three objectives to optimally control the resources allocated to the service stations. Finally, we develop a simulated annealing (SA) algorithm to solve this multi-objective problem, using the goal attainment formulation. We also compare the SA results against the results of a discrete-time approximation of the original optimal control problem, to show the effectiveness of the proposed solution technique.

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1. Introduction

Nowadays, multi-project scheduling is widely used because of the need to consider all projects in the context of an organization as one system where limited resources are shared among multiple projects. Moreover, the project-oriented approach is used in some organizations to schedule operations, and operations are performed depending on the projects. As such, the multi-project management is an attracting widespread attention in project scheduling and management, whereas, conventional project scheduling has focused primarily on single project optimization based on task dependency constraints.

Obviously, scheduling of multi-project systems is more difficult than scheduling of a single project and the problem would be more difficult to schedule when the activity durations are stochastic. On the other hand, in many organizations, not only the activity durations are uncertain, but some new projects are also generated dynamically over the time horizon. In this occasion, multi-project scheduling would be more complex than before. Such a problem is denominated as *“Dynamic PERT Network”* and is suitable for organizations which execute similar projects, for example maintenance projects. Indeed, there are many jobs with a similar structure of activities sharing the same facilities. Although each one acts individually as a single project represented as a classical PERT network, they cannot be analyzed independently since they share the same facilities. Therefore, developing a model under uncertainty and dynamic conditions would be beneficial to scheduling engineers in forecasting a more realistic project completion time.

As the coordination between the projects and departments is rather elaborate in dynamic PERT network, the organizations try to innovate an approach to overcome the challenging tasks of managing and controlling the multi-project environment. For this purpose, a process approach was introduced for dynamic PERT network using simulation by Adler, Mandelbaum, Nguyen, and Schwerer (1995).

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http://dx.doi.org/10.1016/j.ejor.2015.06.038
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They envisioned an organization as a stochastic processing network that consists of a collection of service stations (work stations) or resources, where all projects are considered as one system in that the resources are shared among them. In each node of such a network, one or more identical servers have been dedicated to serve in parallel under a pre-specified discipline. Therefore, the organization's behavior can be modeled as a queuing network, in that each activity is served by a resource, queuing up to reach that resource (in a resource queue), or waiting to join a predecessor activity that is being processed or delayed elsewhere (in a synchronization queue).

Subsequently, the concept of CONWIP (CONstant Work-In-Process) in dynamic PERT networks was studied using simulation by Anavi-Isakow and Golany (2003) who introduced two control mechanisms, in which one mechanism restricts the number of projects, CONPIP (COnstant Number of Projects In Process), and the other puts a limit on the total processing time by all active projects, CONTIP (CONstant Time of projects In Process).

Cohen, Golany, and Shtub (2005, 2007) also studied the resource allocation problem in dynamic PERT network, where it was assumed that the resources can work in parallel, namely, the number of resources allocated to the servers are equal (e.g., mechanical work stations with mechanics, electrical work stations with electricians, etc.). They investigated CONPIP systems using Cross Entropy (CE), based on simulation, and obtained near-optimal resource allocations to the entities that perform the projects.

On the other hand, Azaron and Tavakkoli-Moghaddam (2007) presented a multi-objective model for the resource allocation problem in a dynamic PERT network, where new projects are generated according to a Poisson process and the activity durations are exponentially distributed random variables. They assumed that the capacity of system is infinite, the number of servers in every service station is either one or infinity, the discipline of queues is First Come First Served (FCFS) and the allocated resources affect the mean activity durations. In this regard, Azaron, Katagiri, Sakawa, Kato, and Memariani (2006) and Azaron, Katagiri, and Sakawa (2007) also developed some multi-objective models for the time-cost trade-off problem in classical PERT networks with different assumptions on the distributions of activity durations (exponential in one and generalized Erlang in the other paper) and also different solution techniques (goal programming and goal attainment in one and the interactive SWT technique in the other one). The main difference between this paper and the previous two papers is that here we assume that the similar projects are generated according to a Poisson process over the time horizon which also share the same facilities, but the two previous research works were based on the fact that we have only a one-time job consisting of several activities, as the classical definition of project indicates. Moreover, Azaron, Fynes, and Modarres (2011) proposed an algorithm to obtain optimal constant lead time for each particular project in repetitive (dynamic) PERT networks by minimizing the average aggregate cost per each project. A risk element was also considered in dynamic PERT networks by Li and Wang (2009), who presented a multi-objective model for risk time-cost trade-off problem.

Recently, Yaghoubi, Noori, Azaron, and Tavakkoli-Moghaddam (2011) modeled the resource allocation problem in dynamic PERT networks, where the capacity of system is finite and only one type (class) of projects is generated according to a Poisson process. But in practice, most organizations perform different projects in nature, because of the various projects' requirements, whereas new projects from different classes arrive at system dynamically over the time horizon and are served stochastically. On the other hand, it is not possible to execute too many projects concurrently, because of limited resources. Therefore, the organizations are faced with multi-class dynamic PERT networks with finite capacity problem, as studied in this paper. The introduction of this problem may have a number of practical advantages such as the better utilization of limited resources, positive effects on productivity and easier monitoring of projects from different classes, to multi-project systems especially in engineering environments. In this study, the following assumptions are made:

- The capacity of system is finite.
- Different classes of projects exist in the system.
- New projects from different classes, including all their activities, arrive at system according to independent Poisson processes with different rates.
- Each project's end result leaves the system in its finished form from the sink node of the queueing network.
- Each service station consists of one server and can serve different activities.
- Each activity of any project from every class is performed at a devoted service station.
- Service discipline at each service station is based on FCFS.
- The activity duration at each service station is independent of preceding and succeeding activity durations.
- The activity durations for different classes at each service station are independent and exponentially distributed random variables.
- The queueing network is in the steady-state.
- Mean project completion time and project operating costs are controlled through the resources allocated to service stations.
- The mean times spent in each service station for different classes and the operating cost of the service station, respectively, are non-increasing and non-decreasing functions of the amount of resources allocated to that service station.

For modeling the multi-class dynamic PERT networks with CONPIP, we first consider every class separately and then convert the queueing network of every class into an appropriate stochastic network. By constructing a proper finite-state continuous-time Markov model, a system of differential equations is created to compute the project completion time distribution for any particular project.

In practice, activity duration is considered either as a function of cost or as a function of resources committed to it. In the time-cost trade-off problem (TCTP), which is one of the most important topics in project management, the objective is to determine the duration of each activity in order to achieve the minimum total costs of the project. The TCTP has been investigated using various kinds of cost functions such as linear (Fulkerson, 1961; Kelly, 1961), discrete (Demeulemeester, Herroelen, & Elmaghraby, 1993), convex (Berman, 1964; Lamberson & Hocking, 1970), concave (Falk & Horowitz, 1972) and so on.

As noted before, in this paper, we assume that the mean times spent in each service station for different classes and the operating cost of the service station, respectively, are some decreasing and increasing functions of the resources allocated to that particular service station. According to this, we develop a multi-objective model to optimally control the allocated resources in a way that the total operating costs of the service stations per period and also the mean project completion time over all classes in the steady-state to be minimized. On the other hand, having too many idle servers is not desirable. Therefore, the probability that the system becomes empty in the steady-state is considered as the third objective function, which should be minimized as well. This objective function is equivalent to maximizing the utilization factor of the system, because the utilization factor is the probability that the system is busy in the steady-state. The aim of this paper is to obtain a compromise solution for the resource allocation problem, using the goal attainment technique.

Since the resulting mathematical model is continuous-time, it is too complicated to be solved optimally. Therefore, we develop a simulated annealing algorithm to solve it and then compare the results against the results of a discrete-time approximation of the original optimal control problem to show the effectiveness of the proposed metaheuristic approach, which is another contribution of the paper.

The remainder of this paper is organized as follows. First, we present the literature review in the next section. Then, in Section 3,

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