Advanced Engineering Informatics 24 (2010) 417–427

Contents lists available at ScienceDirect

Advanced Engineering Informatics

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

Task network-based project dynamic scheduling and schedule coordination

Qi Hao *, Weiming Shen, Yunjiao Xue, Shuying Wang

Centre for Computer-assisted Construction Technologies, National Research Council Canada, 800 Collip Circle, London, Ontario, Canada N6G 4X8

ARTICLE INFO

Article history:
Received 17 June 2010
Received in revised form 1 July 2010
Accepted 1 July 2010
Available online 15 August 2010

Keywords:
Resource-constrained project scheduling problem (RCPSP)
Dynamic scheduling
Multi-project scheduling
Schedule coordination
Aircraft maintenance management

ABSTRACT

The resource-constrained project scheduling problem (RCPSP) is an extensively explored area. The existing RCPSP solutions tend to focus on single project scheduling problems without practical supports to address complex constraints, dynamic environments, and multi-project schedule coordination. This paper proposes a dynamic project scheduling algorithm based on partial task network heuristics. This algorithm takes time constraints, resource constraints, and particularly the changing task execution status into consideration. To coordinate conflicting schedules of multiple projects, we proposed an interactive decision support process and developed new algorithms for conflict detection, conflict resolution, and impact analysis. The proposed algorithms have been fully implemented and tested in a web-based aircraft maintenance management system and are being applied in construction for project scheduling and facilities maintenance management.

1. Introduction

Scheduling, as loosely defined by Sule [1], involves defining priorities or arranging activities to meet certain requirements, constraints, or objectives. Project scheduling is less difficult if only precedence relationships constrain the activity schedule. However, in practice, activities do not get completed on their own. Instead, they consume resources in the process. Allocating scarce resources among competing activities adds significant complexity to scheduling, which is known as the resource-constrained project scheduling problem (RCPSP) and is NP-hard in the strong sense [2].

Most research efforts in project scheduling tend to focus primarily on single project scheduling. However, it is essential to extensively address the multi-project scheduling problems because most real life projects involve global resource constraints and the launching of concurrent projects in order to effectively utilize limited resources. The Resource-Constrained Multi-Project Scheduling Problem (RCMPSP) is an extension of the well-known RCPSP problem and it involves the precedence constrained scheduling of two or more projects' activities competing for the same set of scarce resources [3]. RCMPSP is an over-determined problem involving conflicting constraints defined in multiple projects and it is a problem that none of the existing single-project RCPSP approaches can deal with easily.

The RCMPSP problem described in this paper is based on the requirements arising from aircraft inspection and maintenance practices. A regular schedule of maintenance services on an aircraft is very important to ensure that the fleet can serve its missions promptly, properly, and reliably within its designed life cycle. In the periodical inspections and maintenance practice, major "scheduled" inspection/repair tasks require extensive expertise, constant re-assessment of changing priorities, and frequent schedule updates in response to changes in personnel, skill sets, and equipment availability. Aircraft maintenance facilities find it especially challenging to coordinate the schedule of an inspection project with external activities (for example, the receiving schedule of parts-in-order from the supply department) and to resolve conflicts between multiple aircraft inspection projects or crews. Manual coordination of these schedules is very tedious and every aspect can never be taken care of. The dynamic coordination process requires a tool that can involve the input of all the participants and the calculation of all possible effects of any decisions.

The classical RCPSP problem has attracted intense activities for several decades in different academic disciplines and industries. However, all approaches in the literature have been tested in a small set of activities and constraints, which is not comparable to the scale of the RCMPSP problem of aircraft inspection projects specified in this paper. A dynamic project scheduling algorithm, based on partial task networks, is proposed to solve large scale RSPSP problems with complex constraints, such as time, resource and exclusive constraints. This algorithm forms a solid basis for RCMPSP by guaranteeing the validity of the schedule within a project and screening out the complexity when facing multiple projects.

The key to schedule coordination of multiple projects is to detect conflicts and resolve the conflicts through a decision-making process. Multi-project schedule coordination can be achieved

* Corresponding author. Tel.: +1 519 430 7165; fax: +1 519 430 7064.
E-mail addresses: qi.hao@nrc.gc.ca (Q. Hao), weiming.shen@nrc.gc.ca (W. Shen), yunjiao.xue@nrc.gc.ca (Y. Xue), wangvinson@hotmail.com (S. Wang).

1474-0346/$ - see front matter
doi:10.1016/j.aei.2010.07.001

through an interactive approach by considering a reduced constraint set (global constraints) and shifting the schedule of a smaller set of tasks. In general, the basic decision options are: "prioritizing" (projects or tasks), "crashing" (tasks), "shifting" (tasks), and "releasing" (constraints). Whatever the options and choices would be, a manager feels hard-pressed to take action because one cannot foresee the ripple effect of the choices in the long run. To assist human decision makers in project coordination processes, this paper proposes the use of an interactive decision support method to gain the balancing of multiple objectives – time, resources, and performance for the coordination of multiple concurrent projects.

The remainder of the paper is organized as follows: Section 2 provides a review of related literature in RCPSP and RCMPSP; Section 3 specifies the requirements and constraints arising from aircraft inspection and maintenance practices; the RCMPSP problem is then formalized in Section 4; the concept of a partial task network and a task network-based dynamic project scheduling algorithm is described in Section 5; a novel interactive approach for multi-project schedule coordination is proposed in Section 6; Section 7 introduces the developed Web-based aircraft maintenance management system; and the final conclusions are provided in Section 8.

2. Research literature

Plentiful approaches or solutions have been proposed in the literature to solve the RCPSP problem using mathematical modeling, constraint satisfaction, heuristics and meta-heuristics-based computation methods. Herroelen et al. [4] directed readers to several early reviews since the 1960s while the survey itself focused on the recent progress made with optimal branch-and-bound procedures and their important extensions. Based on the review and summary of 200 papers, Brucker et al. [5] proposed a classification scheme according to scheduling environments, activity characteristics, and objective functions to achieve a common notation and classification scheme in the project scheduling domain. Recent overviews of heuristic procedures for the RCPSP can be found in Kolisch and Hartmann [6,7]. Their conclusion is that, in general, meta-heuristic methods outperform rule-based heuristic methods.

Only a few researches have focused on RCPSP problems in the scope of multiple projects. Because of the complexity of RCMPSP problems, priority rule-based heuristics become the only feasible method to construct a feasible algorithm. Katsavounis [3] formulated multiple projects as a single-entry, single-exit weighted directed acyclic graph and applied a single-pass, parallel scheduling heuristic on top of the standard critical path calculation of each individual project. This heuristics-based approach was tested on a small test base with three concurrent projects and 9–12 tasks in each project. Khattab and Soyland [8] believed priority-based rules outperform CPM-based rules used in commercial packages (i.e. Primavera™) in terms of levelling limited resources among multiple construction projects. Meta-heuristic technologies (for example, genetic algorithm models in [9]) are also applied to the multi-project scenario, where multiple projects' schedules are achieved by a combined global objective function above the project level.

A number of researchers have proposed the use of distributed intelligence (specifically, agent technology) to handle the complexity of the RCMPSP problem. A multi-project planning and scheduling system was developed in [10] in which each project in the proposed multi-agent framework is presented physically by a project agent. A negotiation-based planning and control mechanism was developed to coordinate these distributed project agents. However, global shared resources are not addressed; rather, the resources are scheduled and balanced within each project. Brown and McCarragher [11] proposed a negotiation-based distributed resource conflict resolution approach between maintenance agents, process units and other entities in order to coordinate maintenance and production processes in a manufacturing environment. Results have shown reductions in conflict of over 60% compared to a fixed maintenance schedule. DISA (Distributed Interactive Scheduling with Abstractions) [12] employed a dynamic multi-agent architecture to address the uncertainties in real-world domains. Temporal abstractions, in the form of summarizations and generalizations, are applied to agents in different hierarchies for problem reduction and conflict resolution. The system involves the human-in-the-loop through interactive user interfaces and user interactions.

Another community that extensively research into project planning and scheduling is the construction sector. Betts and Lansley [13] reviewed all of the articles published in the Journal of Construction Management and Economics (CME) from 1983 to 1992. They indicated that these articles published by CME are mainly concerned with production-related issues in the construction industry. In the ASCE Journal of Construction Engineering and Management (CEM), the topic of "project planning, scheduling and systems" in the construction domain was comprehensively investigated for the period of 1983–2000 [14,15]. It is identified that the issue of time scheduling is common in construction and "scheduling" is the leading research topic which has received considerable attention internationally with 4.65% of the 879 articles analyzing scheduling-related problems.

More recently, a knowledge map was developed for construction scheduling [16]. Although the target scope is the scheduling solutions in the construction sector, the classification scheme proposed in the knowledge map is useful for general RCMPSP problems. Sriprasert and Dawood [17] developed a Lean Enterprise Web-based Information System that addressed some special needs for project management in construction: multi-constraint information management, visualization, 4D modeling and simulation, mobile data retrieving and data collection, etc. A recent paper [18] questioned the utility of traditional schedule approaches to adequately capture the constraints and complexities of the construction process with respect to schedule generation and management over the course of the project. The authors propose a formal schedule mapping approach to tackle the special problem of distributed schedule coordination between general contractors (GC) and subcontractors (Subs) in typical construction projects. Shen et al. [19] conducted a comprehensive review of integration and collaboration technologies in AEC/FM with BIM and project management being the main integrators for the building's life-cycle processes.

The interactive decision support method proposed in this paper advocates the involvement of humans in the decision-making process. Compared with the approach presented in [12], our solution is based on practical heuristics for conflict detection, project prioritization and conflict resolution; it has no strictly divided hierarchical temporal abstractions and severance of functions between long-term, middle-term, and short-term scheduling horizons. Compared with the scope of [18], our approach tries to achieve true multiple project schedules, instead of integrating a number of distributed schedules into a master project schedule by matching the gaps between terminologies, numbers and level of details of activities.

3. Problem specification

One of the applications of RCMPSP is aircraft inspection and maintenance. In order to maintain an aircraft in a state of "airworthiness", regulations require various kinds of periodical inspections. In periodical inspections, major scheduled inspection tasks need to be performed in a pre-defined order to an aircraft that is temporarily taken off its missions.