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Operations research and dynamic project scheduling: When research meets practice

Mario Vanhoucke

Faculty of Economics and Business Administration, Ghent University, Gent, Belgium
mario.vanhoucke@ugent.be

Operations and Technology Management Centre, Vlerick Leuven Gent Management School, Gent, Belgium
Department of Management Science and Innovation, University College London, London, UK

Abstract. In this study, an overview is given of recent developments in the dynamic project scheduling literature. Both resource-constrained project scheduling and project risk analysis have been widely investigated in the academic literature as useful tools to control projects in progress. Project control has recently received a renewed research attention since the revival of academic publications on earned value management. The integration of academic results in a novel software tool will be discussed from a dynamic scheduling point of view and some practical implications are illustrated. The software tool makes use of state-of-the-art algorithms discussed in the literature and can be used for both commercial and academic purposes. It will be shown that the algorithms implemented in this tool are based on state-of-the-art research results that will be continuously improved by new research results. Therefore, the tool will also be used as a research engine to stimulate future researchers to develop improved algorithms for project scheduling, risk analysis and control. Based on the knowledge obtained from the various research projects discussed in this paper, avenues for future research paths are also discussed to further tighten the bridge between theory and practice in the domain of Operations Research in general and dynamic project scheduling in particular.

Keywords: schedule risk analysis; project management; dynamic scheduling

Introduction

Project management is the discipline of planning, organizing and managing resources to bring about the successful completion of specific project goals and objectives. The project management discipline can be highlighted from various angles and sub-disciplines and contains important issues such as project objective and scope management, human resource management, planning principles, resource allocation models, etc. This article does not aim at providing a general overview on project management, but instead has a clear focus on the planning aspect of projects. The topic of the paper is known as dynamic project scheduling (Uyttewaal (2005) and Vanhoucke (2012a)) to illustrate that project scheduling is a dynamic process that involves a continuous stream of changes in order to support decisions that need to be made along the life of the project. The focus of the paper lies on three crucial dimensions of dynamic scheduling, which can be briefly summarized along the following lines:

- Baseline scheduling: Construct a timetable to provide a start and end date for each project activity, taking activity relations, resource constraints and other project characteristics into account and aiming at reaching a certain scheduling objective.
- Schedule risk analysis: Analyze the strengths and weaknesses of the project schedule in order to obtain information about the schedule sensitivity and the impact of unexpected changes that undoubtedly occur during project progress on the project objective.
- Project control: Measure the (time and cost) performance of a project during its progress and use the information obtained during the scheduling and risk analysis steps to monitor and update the project and to take corrective actions in case of problems.

The outline of this paper is as follows. In the next section, an overview of academic research is given for each of the three dynamic scheduling dimensions. A link to the methodological approach often used in academic research is given and the references used to commercialize these academic endeavors to a commercial project management tool are summarized. In section 3, some practical implementations are listed that highlight the relevance of using Operations Research in project management. In a final section, a general conclusion is drawn and future research paths, for both academics and practitioners, are given to further decrease the discrepancy between Operations Research and real-life applications. Figure 1 illustrates the central theme of this paper: the (often simplified) use of Operations Research methodologies in general and project management and scheduling techniques in particular to feed practical applications, and the feedback loop from practical issues to inspire the development of new algorithms that can be relevant to practice. In this paper, this process will be illustrated using the ProTrack dynamic scheduling software tool.

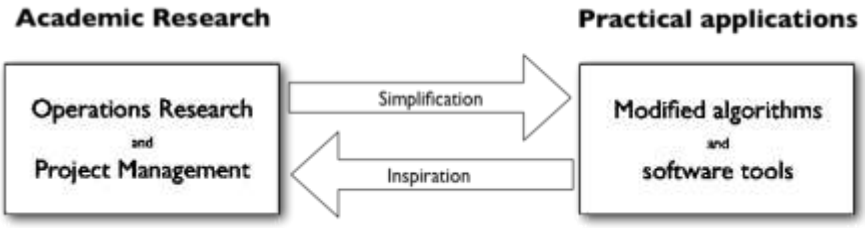

Fig. 1. The central theme of this paper: Theory meets practice

The contribution of this paper and the presentation that will be given at the ICAOR'12 conference is four fold. First, an overview of the recent research efforts will be given on the three dimensions of dynamic scheduling, as published in Vanhoucke (2012a). Secondly, the link between academic research and practice will be shown on a small set of real projects from various companies in Belgium (Europe). Third, a new research tool, called P2 Engine, will be introduced that allow researchers to easily test new dynamic scheduling ideas without a lot of effort. Finally, a preview is given to the future research intentions at the research group of Ghent University in collaboration with different universities and companies.

Academic research

In this section, an overview is given of the previous research projects in dynamic scheduling that have been used for the development of the commercial project management software tool ProTrack (www.protrack.be). In doing so, it is illustrated that academic research endeavors in the field of Operations Research in general and in Project Management in particular are useful stimulators to create a decision support tool for practical settings. It will be shown that a careful selection of promising research results can be easily extended, modified and improved for practical use.

Table 1 gives an overview of the tree dimensions of dynamic scheduling and their relation to the academic literature. The methodology used to create the ProTrack software tool and the main references from the literature are given. The table has no intention whatsoever to give a full literature overview, but instead acts as a summary of the most interesting research papers that have been used during the development of P2 Engine (see later). More details are given in the following three subsections.

Table 1. Overview of the three research topics of dynamic scheduling.

Topic	*Methodology*	*Literature*
Baseline scheduling	Resource-constrained project scheduling using priority rule-based scheduling with single-mode and multi-mode project activities	Demeulemeester and Herroelen (2002), Kolisch and Hartmann (2006), Brucker et al. (1990), Herroelen et al. (1999), Van Peteghem and Vanhoucke (2010), Vanhoucke (2012a), among others
Schedule risk analysis	Monte-Carlo simulation runs on the project baseline schedule	Vanhoucke (2010b, 2011), Hulett (1996), Williams (1992), among others
Project control	Earned Value Management (EVM) and its Earned Schedule (ES) based extensions	Vanhoucke (2010a), Lipke (2003), Fleming and Koppelman (2005), among others

Baseline scheduling

Resource-constrained project scheduling has been a topic in the academic literature for the last decades leading to an overwhelming amount of algorithms and procedures to solve a variety of project scheduling problems. The presence of renewable and nonrenewable resources, the objectives during project scheduling such as the minimization of time, the maximization of the net present value or the leveling of the resource use as well as the presence of single-mode or multi-mode activities has led to the need to build a classification scheme in order to bring structure in the literature (Brucker et al. (1990) and Herroelen et al. (1999)).

The construction of a project baseline schedule can be done in various ways, ranging from simple single-pass heuristics to advanced meta-heuristic solutions and even exact algorithms. ProTrack's project baseline scheduler makes use of priority based scheduling tools (Kolisch and Hartmann (2006)) using a serial generation scheme. It can cope with single-mode (fixed activity durations) as well as multi-mode (fixed work activities) activities as investigated by Van Peteghem and Vanhoucke (2010), among others. An overview of algorithms to generate resource-constrained project baseline schedules is given in the books by Demeulemeester and Herroelen (2002) and Vanhoucke (2012a).

Schedule risk analysis

Since the introduction of the well-known PERT and CPM techniques in the late '50s in project scheduling, research on measuring a project's sensitivity has increasingly received attention from both practitioners and academics. This interest is inspired by the observation that a schedule obtained by the CPM assumes that the durations and precedence relations of the project activities are known with

certainty. Reality, however, is flavored with uncertainty, which renders the critical path method inapplicable for many real-life projects. Consequently, despite its relevance in practice, the PERT/CPM approach often leads to underestimating the total project duration, which obviously results in time overruns in practice.

The technique known as Schedule Risk Analysis (SRA, Hulett (1996)) connects the risk information of project activities to the baseline schedule and provides sensitivity information of individual project activities as a way to assess the potential impact of uncertainty on the final project duration and cost (Vanhoucke (2010b)). More precisely, it measures the sensitivity of project activities and the potential impact of changes in the baseline schedule on the overall project objective.

Measuring risk of a project baseline schedule using Monte-Carlo simulation has been investigated in literature by Williams (1992) and many others. The interest in schedule risk analysis from both the academics and the practitioners lies in the need of the project manager to focus his/her attention on those activities that influence the performance of the project. When management has a certain feeling of the potential impact the various activities might have on the project objective, a better focus and a more accurate response during project control should positively contribute to the overall performance of the project.

Project control

In the previous sections, it was assumed that the project has not started yet, and hence, the project was still in the preparation phase. In this section, it is assumed that the project has started and that the project is in progress. Consequently, it is the task of the project manager to carefully control the performance of the project, using his/her knowledge of the schedule risk analyses and baseline scheduling steps discussed in the two previous sections. The project control dimension of dynamic scheduling can be done relying on a well-established technique known as Earned Value Management (Fleming and Koppelman (2005)).

Earned Value Management (EVM) is a methodology used since the 1960s, when the USA department of defense proposed a standard method to measure a project's performance. The system relies on a set of often straightforward metrics to measure and evaluate the general health of a project. These metrics serve as early warning signals to timely detect project problems or to exploit project opportunities. The purpose of an EVM system is to provide answers to project managers on questions such as:

- What is the difference between budgeted and actual costs?
- What is the current project status? Ahead of schedule or schedule delay?
- Given the current project performance, what is the expected remaining time and cost of the project?

Recently, an extension has been proposed by Lipke (2003) known as Earned Schedule, which better reflects the real time performance of a project. In Vandevoorde and Vanhoucke (2006), it has been shown that the Earned Schedule technique outperforms the traditional Earned Value Management technique when it comes to measuring and predicting the final duration of a project in progress.

Practical implementations

While in the previous section an overview was given of the academic results that have been used to build the commercial project management software tool, this section will put a focus on the practical implications that has been encountered during the development of the ProTrack software tool and the results that have been obtained thanks to the academic research.

Research handbook

During the development of the novel software tool and the implementation of the academic results into the software, all work has been carried out in the light of a research project funded by both academic institutions (Ghent University) and commercial organizations (e.g. member organizations of PMI-Belgium (www.pmi-belgium.be)). The results have been published in the book "Measuring Time" (Vanhoucke (2010a)), which clearly shows that academic research and practical relevance should and can go hand in hand. The book has been awarded by academic and professional organizations, which has undoubtedly tightened the bridge between academic research and practical relevance.

Empirical evidence

Academic research has little or no value if it cannot be tested empirically in order to validate its relevance for practitioners. Therefore, the results obtained on fictitious project data published in Vanhoucke (2010a) have been compared and validated with additional tests performed on a set of real-life data from 8 Belgian companies from various sectors (Vanhoucke (2012b)). In this study, it has been shown that both the baseline scheduling step and the schedule risk analyses are useful tools to measure the project performance of a project in progress and to improve the project control process and the corrective action decision making process in case the project is in danger.

Research tool

Since research is an ongoing process, the tool has also been translated into a research tool in order to stimulate further research in this domain. The tool is a command line- and platform-independent extension of ProTrack, based on the LUA language (www.lua.org) that can be used by researchers to test their novel ideas in project management. Using the LUA scripting language, the researcher can write his/her own dynamic scheduling tests and can automatically make use of the state-of-the-art algorithms implemented in the software to generate project data, to construct baseline schedules, to analyze the project risk, to artificially control the project performance and much more. In doing so, we hope we have given the students and

researchers a tool to apply the Operations Research methodologies and project management techniques in their research projects in order to improve the existing knowledge and move the project management discipline to a higher level. This tool, called P2 Engine (www.p2engine.com), will be illustrated during the ICAOR'12 conference.

Conclusions

Academic research and empirical relevance is what brings researchers and practitioners together to advance the current state-of-the-art methods and methodologies. Operations Research in general and project management in particular have been widely investigated from various angles and for different purposes. In this paper, an overview is given of the academic endeavors that have led to publications in the domain of project management and dynamic scheduling and their specific use and relevance during the development of a new commercial software tool.

It is worth noting that new research is on its way. Recently, a new research project titled "searching for static and dynamic project drivers to predict and control the impact of management/contingency reserve on a project's success" has been awarded for a Concerted Research Actions (CRA) grant by Ghent University (Belgium). This "more than a million euro" research project in collaboration with international universities in the US and the UK and with CERN (Switzerland) will certainly move the research in project management and dynamic scheduling towards a higher level. Preliminary research results will be spread on conferences, such as the www.evm-europe.eu conference. Active collaborations with the Project Management Institute (www.pmi.org) and its Belgian chapter (www.pmi-belgium.be) are guaranteed. The target of the researchers is to publish in flagship academic journals, to present on international conferences as well as to continuously tighten the bridge between academic research and practical relevance. During the presentation, a preview of these future research challenges will be given.

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