ABSTRACT

In this manuscript, an overview is given of the activities done at the Operations Research and Scheduling (OR&S) research group of the faculty of Economics and Business Administration of Ghent University. Unlike the book published by Vanhoucke (2014a) that gives a summary of all academic and professional activities done in the field of Project Management in collaboration with the OR&S group, the focus of the current manuscript lies on academic publications and the integration of these published results in teaching activities. An overview is given of the publications from the very beginning till today, and some of the topics that have led to publications are discussed in somewhat more detail. Moreover, it is shown how the research results have been used in the classroom to actively involve students in our research activities. A clear focus is put on Integrated Project Management. The connection between research and teaching is mainly made in the Business Engineering programme at Ghent University and MBA teaching at Vlerick Business School. The connection between teaching activities and the practical business world is mainly made by OR-AS, a company providing free versions of two commercial software tools and a business game to the students. Finally, EVM Europe is an organisation that aims at connecting the research activities to the business world by organising a yearly event where “research meets practice”.

The purpose of this paper is to give a full summary of all research work done at the OR&S research group. Although it is recognised that a lot of excellent research on the Project Management theme is done at various institutions in the world, no other reference than the OR&S references will be given. Hence, this article is not intended to give a literature overview nor a summary of state-of-the-art research, but instead to present a context of the last decade(s) on the work done at the OR&S group. Therefore, the target audience of this article consists of colleagues and friends, stu-

services to approximately 2,500 full-time students as well as to the community in the fields of economics, business economics and business engineering.2

Vlerick Business School is a leading international business school and offers fully-accredited, world-class education programmes combining a healthy mix of theoretical knowledge and practical insight. It is a leading academic institution with a strong tradition of innovative and independent research, and is consistently ranked among the top business schools in Europe and the world.3

All work presented in this article is done at one of these two institutions, often in collaboration, seldom in separation, in order to illustrate the link between research and teaching on the one hand and between teaching and practice on the other hand. Making these connections is crucial to get the students involved in the themes of the courses and better prepares them for their future career.

Figure 1 graphically illustrates the three connections that comprise the topic of this article. The connection between research and teaching is mainly made in the Business Engineering programme at Ghent University and MBA teaching at Vlerick Business School. The connection between teaching activities and the practical business world is mainly made by OR-AS, a company providing free versions of two commercial software tools and a business game to the students. Finally, EVM Europe is an organisation that aims at connecting the research activities to the business world by organising a yearly event where “research meets practice”.

The papers presented in this article can be used as a summary for students who want to join our group. As a regular student during a group work in one of the courses at the Business Engineering programme, for a master thesis, as a PhD student, or in any other collaborative way.

The outline of this article is as follows. Section 2 gives an overview of the research papers written at the OR&S group till today. All papers will be ranked by year and a short summary of the process resulting in the publication outcome will be given. In section 3, the same papers will be classified into different topics, from Project Management and Scheduling to Personnel Scheduling or in any other collaborative way.

The connection between research and teaching is consistently ranked among top business schools.

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INTRODUCTION

A university is an institution of higher education and research which grants academic degrees in a variety of subjects. It prepares young people for the outside world on the job market and a future career in a variety of business and/or research environments. The Operations Research and Scheduling (OR&S) group is a research group1 that is active at the Faculty of Economics and Business Administration of Ghent University and carries out research in collaboration with various companies, colleagues from international research groups and Vlerick Business School. The faculty of Economics and Business Administration of Ghent University (Belgium) boasts a dynamic team of about 270 employees offering theoretically grounded, high-quality and socially relevant education, research and scientific

1 www.projectmanagement.ugent.be.
2 www.projectmanagement.ugent.be.

1. The papers

1.1 The past

Before 2000:

The years before the 21st century were the years when I was introduced to the world of Operations Research and Project Management. It was a journey through the literature searching for a problem that is complex and challenging. The literature on project

1 www.projectmanagement.ugent.be.
2 www.projectmanagement.ugent.be.
RESEARCH REVIEW /// BLENDED LEARNING IN PROJECT MANAGEMENT  
AN OVERVIEW OF THE OPERATIONS RESEARCH ...  

scheduling was full of these problems. After a few years of searching and developing new algo- rithms and techniques, the publication on the discrete time/cost trade-off problem (DTCTP) using the branch-and-bound technique based on the Fullerson labeling algorithm was published in Demeneuve et al. (2006). More than a decade later, the algorithm is still very relevant since it is used to calculate optimal solutions for time/cost trade-off decisions. Inspired by the principle of just-in-time production, a set of activities was developed that could linearly depend on the start or finish time of activities. This led to the development of a project data generator, known as RandGen (random network generator). A first version of this generator is published in Demeneuve et al. (2003).

Meanwhile, various algorithms have been developed for extensions of the RCPSD-DC, such as the optimisation of progress payments in projects published by Vanhoucke et al. (2003) and a case study with real project data from a water purification company in Belgium as shown in Vanhoucke and Demeneuve (2003). In that year, a Dutch article on the RCPSD-DC was published in Vanhoucke (2003).

2004: 2004 was a bad year for science since we were not able to publish a single article. I guess we were just working hard on article revisions and/or preparing new articles to be published in 2005 and later on. In 2005, two extensions on the DTCTP were developed. A first extension presents new computational results with time switch constraints (Vanhoucke, 2005) while a second one is the development of a student game, known as the Project Scheduling Game (PSG) with time/cost trade-offs (Vanhoucke et al., 2005).

2005: 2005 was also the year in which the first algorithm was developed for the basic problem type (RCPSD), resulting in a bia-popula- tion meta-heuristic solution method developed by Debels and Vanhoucke (2005). Many other algorithms have followed in later years. As a side track, an introduction to project control was written on supply chain management in the Management Jaarboek (Vanhoucke and Deschoolmeester, 2005).

2006: 2006 was a turning point for research in OR&S. Results thanks to the growing number of publications and the variety of research topics. Thanks to the development of two new solution methods for the RCPSD, a scatter search method (Debels et al., 2006) and an electromag- netic solution approach (Debels and Vanhoucke, 2006), we were able to deliver the currently best known solutions in the literature. Extending the knowledge and available pro- cedures of resource constrained project sched- uling was full of these problems. After a few years of searching and developing new algo- rithms and techniques, the publication on the discrete time/cost trade-off problem (DTCTP) using the branch-and-bound technique based on the Fullerson labeling algorithm was published in Demeneuve et al. (2006). More than a decade later, the algorithm is still very relevant since it is used to calculate optimal solutions for time/cost trade-off decisions. Inspired by the principle of just-in-time production, a set of activities was developed that could linearly depend on the start or finish time of activities. This led to the development of a project data generator, known as RandGen (random network generator). A first version of this generator is published in Demeneuve et al. (2003). Meanwhile, various algorithms have been developed for extensions of the RCPSD-DC, such as the optimisation of progress payments in projects published by Vanhoucke et al. (2003) and a case study with real project data from a water purification company in Belgium as shown in Vanhoucke and Demeneuve (2003). In that year, a Dutch article on the RCPSD-DC was published in Vanhoucke (2003).

The growing number of algorithms for the RCPSD and its extensions created a certain aware- ness that these algorithms only construct project sche- 2001: In the early years of the 21st, the project scheduling literature was mainly devoted to solving solution methods for the so-called resource-constrained project scheduling problem (RCPSD). In this problem, a set of activities needs to be scheduled within the limited available resources such that the total time is minimised. Instead of focusing on this classic and challenging optimisation prob- lem, I chose to put all my research effort on an extension of this problem type by adding activity cash flows. Rather than minimising the total project duration, the objective was to maximise the net present. This problem is known as the resource-constrained project scheduling problem with discounted cash flows (RCPSD-DC). The rele- 

The research on project control was at full speed in 2008, leading to two publications in pop- ular magazines (Vanhoucke, 2008b; Vanhoucke and Vanhoudeweg, 2008) and an award in Rome by the International Project Management Association (Vanhoucke, 2008a).

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The NSP has further been investigated, leading to the development of an electromag- netic solution method (Debels and Vanhoucke, 2006) and a data generator to automatic- cally create data for testing known as the NSP Library NSPLib (Vanhoucke and Maenhout, 2007).

Totally new to the OR&S group was the use of Operations Research techniques in a Manage- ments Accounting settings. The hard work during the summer in London and the simulation of accounting errors led to a publication in The Accounting Review (Labro and Vanhoucke, 2007) and soon another publication would follow. As a side track, an introduction to the use of blended learning was published in Dutch by Vanhoucke (2007a).

2007: The RCPSD and its extensions were still on the research ra- dios of OR&S. In Debels and Vanhoucke (2007), a decomposition based heuristic for the RCPSD was published in the flagship Operations Research journal. This algorithm was the first heuristic for the DTCTP and its extensions was published in Vanhoucke and Debels (2007). Moreover, the relevance of the RCPSD-DC has been shown by Vanhoucke (2007b) for the Westerschelde tunnel project at the Netherlands. The research to project control and EVM started to lift off thanks to a simulation study written by Vanhoucke and Vanhoudeweg (2007b) and an acceptance in an American pro- fessional journal “The Measurable News” (Vanhoucke and Vanhoudeweg, 2007a).

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2008: The study in Management Ac- counting and its robustness for errors led to a sec- ond publication in Labro and Vanhoucke (2008). Similarly, the need for the au- tomatic generation of project data led to a second version of RanGen in Vanhoucke et al. (2008).

The RCPSD research has been extended to more realistic problem definitions. A search of the impact of activity assumptions on the resource use resulted in the publication in Vanhoucke and Debels (2008) while the presence of setup times and fast tracking was investigated by Vanhoucke (2008c).

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After a few publications on the NSP, it was about time to characterise the problem and its generated instances in Vanhoucke and Maenhout (2009). Meanwhile, the impact of nurse characteristics on cyclic scheduling for the NSP was published in Maenhout and Vanhoucke (2009). This has been discussed during the last years on optimising very complex and challenging problems was illustrated on the production problem at Arcelor Mittal in Vanhoucke and Debels (2010).

2010: The RCPSP-DC has never been forgotten at OR&

S, and this a scatter search procedure to construct the best-known solutions was developed by Vanhoucke (2010a). Likewise, the RCPSP-MM is solved by a genetic algorithm allowing activity splitting (Van Peteghem and Vanhoucke, 2010). The research on project control gradually became more mature and 2010 was the year to link the EVM methods with Schedule Risk Analysis (Vanhoucke, 2010b) in order to focus on an integrated project control approach. All the work on project control was summarised in the book “Measuring Time” Vanhoucke (2010b) and proposed in Vanhoucke (2010c). A software tutorial on ProTrack, the PM tool that is used by almost all the Project Management students at the Faculty of Economics and Business Administration, is available at Vanhoucke and Van Acker (2010).

The development of a branch-and-bound procedure for the NSP was done by Maenhout and Vanhoucke (2010a) and the experience in personnel scheduling was extended to the airline sector using a scatter search algorithm (Vanhoucke and Vanhoucke, 2010b). Thanks to the success of the Business Engineering program at Ghent University and the need to illustrate the relevance of Operations Research and Project Management students at Vlerick Business School, a student model to assign exams to students working in groups was developed and published in Vanhoucke (2010a).

2011: 2011 was yet another year to extend the focus and the research direction. Using Operations Research methods for manufacturing problems led to the development of meta-heuristics for the single machine scheduling problem (Sels and Vanhoucke, 2011) and the job shop scheduling problem (Sels et al., 2011a), and their relevance was illustrated on a case study in a production company (Sels et al., 2011b).

Despite this change in research direction, the good old traditional research topics had not disappeared, and the NSP was described by Vanhoucke and Maenhout (2011b), while an overview of simulation methods to test the accuracy of project control methods was discussed in Vanhoucke (2011c). An overview of the second edition of this journal is given in Vanhoucke (2011d). The research on project control gradually became more mature and 2010 was the year to link the EVM methods with Schedule Risk Analysis (Vanhoucke, 2010b) in order to focus on an integrated project control approach. All the work on project control was summarised in the book “Measuring Time” Vanhoucke (2010b) and proposed in Vanhoucke (2010c). A software tutorial on ProTrack, the PM tool that is used by almost all the Project Management students at the Faculty of Economics and Business Administration, is available at Vanhoucke and Van Acker (2010).

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Baseline scheduling: Constructing schedules for projects has been the topic since the first paper published in 1958 and will be a never-ending topic of research in the future. Resource-constrained project scheduling algorithms with time, net present value, work content, or other objectives as well as with extensions to setup times, to multiple modes and cost trade-offs have been investigated at the OR&S research group. The RCPSP has been investigated under different optimisation objectives and/or activity extensions as summarised along the following lines:

- **RCPSP**: Minimising the total duration of the project with limited resources is done in Debeck and Vanhoucke (2005); Debeck et al. (2006b); Debels and Vanhoucke (2006; 2007); Vanhoucke and Debels (2008); Vanhoucke and Maenhout (2010b).
- **RCPSP-DC**: Maximising the net present value using discounted cash flows and various cash flow models is done in Vanhoucke et al. (2007c, 2000b); Vanhoucke and Demeulemeester, 2003; Vanhoucke, 2003, 2006a, 2008, 2009a; 2010b; Vanhoucke and Maenhout, 2010b.
- **RCPSP-WET**: Minimising the weighted tardiness penalty costs is done in Vanhoucke et al. (2004a).
- **RCPSP-PC**: The minimisation of the idle time of resources using so-called work consistency constraints was investigated in Vanhoucke, 1996d, 1997a.
- **RCPSP-QTS**: Optimising the timing of activities by incorporating quality dependent time slots was presented in Vanhoucke, 2006c.
- **RAFC**: The resource availability cost problem determines the optimal level of resource consumption using a so-called resource balancing algorithm developed by Van Peteghem and Vanhoucke, 2007b.
- **RCPSP-MM**: Extending the RCPSP to multiple activity duration options for activities extends the problem to the RCPSP-MM and is analysed by Van Peteghem and Vanhoucke, 2009, 2010a, 2010b, Cleemput and Vanhoucke, 2011; Van Peteghem and Vanhoucke, 2010b.
- **NSP**: Most of the work done in the OR&S is related to the NSP. The problem is the problem of determining a work schedule that minimises the cost of a project, subject to project constraints and the availability of resources, the so-called job shop scheduling problem. The problem is NP-hard in the strong sense and has been investigated widely in the literature.

### 2.1 Dynamic scheduling

The term dynamic scheduling is used to refer to the interaction between control and the process. In this approach, the project characteristics into account, and aiming to reach a certain scheduling objective.

### 2.2 Personnel scheduling

Data generation: The need for data in research was previously explained in section 3.1. Similar to project data, a data generator for nurse scheduling problem instances was developed by Vanhoucke and Maenhout, 2007. This so-called NSPlib problem set can be downloaded from www.projectmanagement.ugent.be. The data was characterised using complexity metrics described in Vanhoucke and Maenhout, 2009.

### 2.3 Machine scheduling

Single and parallel machine scheduling is an Operations Research discipline that is related to the RCPSP discussed earlier and is the problem of assigning a group of jobs to one or multiple machines, subject to constraints and preferences. These problems have been investigated widely in the literature and examples include the classical single and parallel machine scheduling problems (SMP and PMP) and the crew scheduling problem (CSP) in airline companies, published in (Maenhout and Vanhoucke, 2010b, 2011a).

### 2.4 Management accounting

The relevance of Operations Research techniques in the area of management accounting has been investigated widely, and examples include the study on the impact of errors in man-agement accounting systems published in (Vanhoucke, 2007, 2008).
2.5 Case studies

Although not the primary focus of academic research, many of the results have also been validated on real data, in a real business settings or at least in controlled setting using empirical data. These case studies show the relevance of the research efforts done at OR&S and they are an ideal tool to present our research results to a broader audience.

- Water production: The relevance of optimising cash flows using the net present value was illustrated on a case study of the Vlaamse Maatschappij voor Watervoorziening published by Vanhoucke and Demeulemeester (2003).

- Westerdamse tunnel: The use of work continuity constraints in a tunnel construction project to optimise the idle time of a freezing machine is shown in Vanhoucke (2007b).

- Project control: The alternative control methods were developed and tested in a pre-thesis research and were validated on real project data from 8 Belgian companies in Vanhoucke (2016).

- Steel production: The optimisation of a steel production schedule at Arcelor Mittal by using heuristic solution methods is shown in Vanhoucke and Debels (2009).

- Exam modeling: The assignment of case studies to students who have to solve this case in groups is used at Vlerick Business School and is described in Vanhoucke (2010a).

- Nurse scheduling: The optimisation of nurse schedules at the University hospital in Ghent (Belgium) is described by Maenhout and Vanhoucke (2009, 2013a).

- Crew scheduling: The use of algorithms to assign pilots to airplanes was illustrated by Maenhout and Vanhoucke (2009, 2012b) and is used by students following a Project Management course at Ghent University as well as for the MBA students and participants in commercial trainings at Vlerick Business School. In most of the Project Management and Operations Research courses, a system known as "blended learning" is used, combining face-to-face classroom methods with online learning and computer-mediated business games. Research plays a central role in this system, since it is mostly the driver for innovation in our teaching methods. Although it is hard to specify which paper has exactly contributed to the teaching sessions, a summary of the most important connections between the research results and use in the classroom is given.

Background reading: The most obvious way to integrate research in teaching activities is to put the papers available to students such that they can use them as background or study material. In the course "Project Management", the papers on the business game (Vanhoucke et al., 2005) and the illustrative consultancy projects (Vanhoucke and Demeulemeester, 2003; Vanhoucke, 2007b, 2012b) are optionally used as background material. In the course "Applied Operations Research", the personnel scheduling paper Maenhout and Vanhoucke (2009) is used as supportive study material for students to construct their own personnel schedule.

Case studies: Some of the research results have been translated into case studies. They are used in class exercises, such as the Thutum-Paran’s II bridge project case studies (A, B and C) published in Vanhoucke (2012d). One of the courses at Ghent University contains one big integrated group exercise, known as the Mutum-Paraná II bridge case project studies (A, B and C) published in Vanhoucke (2012d). One of the courses at Ghent University contains one big integrated group exercise, known as the Thutum-Paran’s II bridge project case studies (A, B and C) published in Vanhoucke (2012d). One of the courses at Ghent University contains one big integrated group exercise, known as the Mutum-Paraná II bridge project case studies (A, B and C) published in Vanhoucke (2012d). One of the courses at Ghent University contains one big integrated group exercise, known as the Mutum-Paraná II bridge project case studies (A, B and C) published in Vanhoucke (2012d). One of the courses at Ghent University contains one big integrated group exercise, known as the Mutum-Paraná II bridge project case studies (A, B and C) published in Vanhoucke (2012d). One of the courses at Ghent University contains one big integrated group exercise, known as the Mutum-Paraná II bridge project case studies (A, B and C) published in Vanhoucke (2012d). One of the courses at Ghent University contains one big integrated group exercise, known as the Mutum-Paraná II bridge project case studies (A, B and C) published in Vanhoucke (2012d). One of the courses at Ghent University contains one big integrated group exercise, known as the Mutum-Paraná II bridge project case studies (A, B and C) published in Vanhoucke (2012d).

- Vulpokine: The relevance of the job shop scheduling problem to optimise the production of a Belgian furniture manufacturing company producing industrial wheels and castors in rubber is demonstrated by Selis et al. (2008).

- Knitted Fabrics: A metaheuristic search is implemented to optimise the production of a Belgian knitted fabric company is published in Kerkhof and Vanhoucke (2014).

3. Blended learning: No teaching without research

The primary goal of research is to publish in high quality international journals and to present

the research results in well-known and recognised conferences across the world. However, at OR&S, a secondary goal is to make a link between the research results and their use in teaching for our Business Engineers at the Faculty of Business Administration of Ghent University as well as for the MBA students and participants in commercial trainings at Vlerick Business School.

In most of the Project Management and Operations Research courses, a system known as “blended learning” is used, combining face-to-face classroom methods with online learning and computer-mediated business games. Research plays a central role in this system, since it is mostly the driver for innovation in our teaching methods. Although it is hard to specify which paper has exactly contributed to the teaching sessions, a summary of the most important connections between the research results and use in the classroom is given.

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4. Conclusions

In this paper, an overview is given of the research activities and publications over the last 15 years carried out at the Operations Research and Planning Group (ORPG) research group of the Faculty of Economics and Business Administration of Ghent University, in collaboration with the work done at Vlerick Business School. A flashback on the past activities was conducted in a chronological order and the work was classified along the various topics that have been investigated at the OR&S’s group. A link with teaching activities has been made to show that research can be used as a supportive tool in teaching activities at universities and business schools. A short look forward into the future has been made to show that future research in on its way. Figure 2 displays a classification of most of the OR&S publications along six different research areas that have been used along the following lines:

**Topic (general):** The main topics are Management Accounting (MA), Machine Scheduling (MS), Project Management (PM) and Personnel Scheduling (PS). The two re-maining topics lie in Operations Research (OR) when specific OR methods are used but the topic does not belong to the previous four topics, and a rest class (Other) for various other topics.

**Topic (specific):** The topics are specified in more detail using abbreviations that have been used throughout this article. RCPSP is used to refer to an extension of the RCPSP, excluding the RCPSP-D.C (that has a separate label). The abbreviation GEN is used to refer to data generation methods discussed in section 3.1 and MA to refer to Management Accounting publications (section 3.4).

**Teaching:** The use of the publications in teaching activities can be done in various ways. The papers can be used in business games (BG), as background material (BM), study material (SM) or optional reading (OR) or for master theses (MT). Other papers have indirectly (I) contributed to our activities or are simply not used (NI).

**Solution method:** The methods used to solve problems can be classified as exact methods (Exact) that guarantee optimal solutions or heuristic methods (Heur). Other studies make use of simulations (Sim) or generation of data (Gen). Case studies are also classified (Case) and a remaining portion (Other) did not use any OR technique.

**Journal classification:** International peer-reviewed journal can consist of articles in web of science (A1) or other articles (A2). National peer-reviewed journals are classified in A3.

The label A is used for journal articles that cannot be classified in A1, A2 or A3. Books as authors are classified in B1 and book chapter as authors in B2. P1 is used for a proceeding in a web of science journal (mainly Lectures Notes in Computer Science).

**Year of publication:** A summary of section 2.1 is displayed in the last two columns. Obviously, over time new research endeavours will be published in the academic literature, and integrated in our teaching activities. Therefore, this article will be updated continuously with the new publications and research outcomes in various ways, and the latest changes will be put available at www.or-as.be/books.
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