

Do Research, Create Knowledge, Feed Your Talent.

A Summary of Research at Operations Research & Scheduling

Mario Vanhoucke



Foreword

Research is a process to discover new knowledge, and publishing its results is an integral part of a researcher's professional life. The dissemination of research findings is an integral part of the research career in academia, and aims at sharing results with professionals and academics to stimulate the use of the new findings and the enhancement of the current results to find further improvements.

Research groups at universities often focus on a small set of academic problems and provide results published in international papers, book chapters, conference proceedings, professional articles and summary books. While the members of the research group obviously have a good overview of what has been done in the past, and what are the promising areas for future researchers, outsiders (other researchers) often don't see the complete picture of the track record and the work done at the particular research group.

The purpose of this book is to give an overview of the work done at the Operations Research & Scheduling (OR&S) group. This research group works at the faculty of Economics and Business Administration of Ghent University (Belgium), in close collaboration with Vlerick Business School (Belgium), and UCL School of Management of University College London (UK). The group also maintains collaborations with the Universidade Aberta (Portugal), and the laboratory of Artificial Intelligence and Decision Support of the Institute for Systems and Computer Engineering - Technology and Science (INESC TEC, Portugal).

The main research topics of the OR&S group lie in the development of quantitative tools for project management, machine scheduling and personnel scheduling, but occasionally, the quantitative methodologies have been used in other areas such as healthcare optimization and management accounting. It has resulted in a number of publications in international journals, but also in professional articles, book chapters and a number of books. Each individual page of this book has been devoted to exactly one publication, each time mentioning key data of the publication such as the keywords, the reference, the abstract and some links to interesting material to obtain the full work.

The main reasons why the work has been collected in this book are threefold. First, the book is intended to provide a full overview to researchers about the activities and research results obtained at the OR&S group. It is seen as a guide to find the relevant sources in literature, and hopefully to stimulate the use of the research findings for their own future research. Regular book updates with new research findings and publications will be provided upon availability. A second purpose of this book is to have an internal overview of the activities, not only for our own new researchers to find their way in the research world of OR&S but also out of pride to show what our group has been done in the past decade(s). Finally, the book is also a way to express my gratitude to the various people who joined (and then left) the group. These researchers all contributed to this book in one way or another, by working under my supervision, in good times and in bad times, and by spending their valuable time in a never-ending search towards improved results. That is, after all, the life of a researcher. It is a search and a discovery of new knowledge, with a lot of failures and rare moments of success.

Mario Vanhoucke

January, 2016

Table of contents

I Academic articles	5
Contract design	6
Payment models	7
Logical constraints	8
Artificial intelligence	9
Big data	10
Empirical database	11
Empirical evaluation	12
State-of-the-art forecasting	13
Custom packs design	14
Comparing control methods	15
Empirical distributions	16
Statistical project control	17
Multivariate project control	18
Cash flow models	19
Homogeneous workforce	20
Scheduling & Staffing	21
Unrelated machines	22
Resource renting	23
Operating theatre	24
Multivariate regression	25
Learning in projects	26
Earned value stability	27
Journal classification	28
Project control	29
Schedule risk analysis	30
Decomposition heuristic	31
Control tolerance limits	32
Knitted fabrics	33
Hybrid machine scheduling	34
Rostering & scheduling	35
Experimental investigation	36
Support vector machines	37
Blended learning	38
Student learning	39
PMI Belgium's recognition	40
Nurse staff allocation	41
Reconstructing nurse schedules	42
Analyzing nurse schedules	43
Resource availability cost	44
Simulation overview	45
Scheduling experience	46
Artificial nurse rostering	47
Efficiency improvement	48
Family setup times	49
Priority rules	50
Control efficiency	51

Operations Research	52
RCPSp & SAT	53
Evolutionary rerostering	54
Job shop scheduling	55
Industrial wheels	56
Risk & control	57
Resource scarceness	58
Single machine scheduling	59
Branching strategies	60
Nurse rerostering	61
Network topology	62
Fixed activity cash flows	63
Activity preemption	64
Exam case distribution	65
Cyclical scheduling	66
Artificial nurse data	67
Arcelor Mittal	68
Artificial immune system	69
Genetic cash flow algorithm	70
Diversity in costing systems	71
Comparing crossovers	72
Generating networks II	73
Activity assumptions	74
Fast tracking	75
Decomposed resource scheduling	76
Errors in costing systems	77
Electromagnetic nurse scheduling	78
Evaluating earned value	79
Time/cost extensions	80
Westerschelde tunnel	81
Electromagnetic search	82
Decomposing problems	83
Nurse scheduling	84
Comparing earned value	85
Hybrid search algorithms	86
Work continuity constraints	87
Quality dependent time slots	88
Bi-population genetic algorithm	89
Project scheduling game	90
Time-switch constraints II	91
Generating networks I	92
Progress payments	93
Water production scheduling	94
Time-switch constraints I	95
Linear time dependencies	96
Net present value	97
Earliness/tardiness	98
Time/cost optimization	99

II Professional articles	100
Duração agregada	101
Communication experiments	102
Earned duration	103
Controles de projetos	104
Book review	105
Schedule adherence	106

Risk & earned value	107
Adding value	108
Performance management	109
Topological structure	110
Accuracy & criticality	111
Forecast accuracy	112
 III Book chapters	 113
Logic & scheduling	114
Heuristics cost optimization	115
Generalized trade-offs	116
Managing cost	117
Adherence & rework	118
Solution strategies	119
Intensification & diversification	120
Crew scheduling	121
Accuracy determinants	122
 IV Books	 123
PM Knowledge Center	124
Work & passion	125
Decision making	126
Integrated project control	127
Dynamic scheduling	128
Measuring time	129
PM software	130

Part I

Academic articles

Incentive contract design for projects: The owner's perspective

Kerkhove, Louis-Philippe; Vanhoucke, Mario

Tags

contract design; project management; simulation

Reference

Kerkhove, L. and Vanhoucke, M. (2016). Incentive contract design for projects: The owner's perspective. *Omega The International Journal of Management Science*, To Appear

DOI

10.1016/j.omega.2015.09.002

Classification

International peer-reviewed journal; Written for researchers; Dataset available at www.projectmanagement.ugent.be



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Contract design

Due to the adoption of more and more complex incentive contract structures for projects, designing the best contract for a specific situation has become an increasingly daunting task for project owners. Through the combination of findings from contracting literature with knowledge from the domain of project management, a quantitative model for the contract design problem is constructed. The contribution of this research is twofold. First of all, a comprehensive and quantitative methodology to analyse incentive contract design is introduced, based on an extensive review of the existing literature. Secondly, based on this methodology, computational experiments are carried out, which result in a set of managerial guidelines for incentive contract design. Our analysis shows that substantial improvements can often be attained by using contracts which include incentives for cost, duration as well as scope simultaneously. Moreover, nonlinear and piecewise linear formulae to calculate the incentive amounts are shown to improve both the performance and robustness across different projects.

*Theorems are just guesses made
by scientists*
José Coelho



Payment models and net present value optimization for resource-constrained project scheduling

Leyman, Pieter; Vanhoucke, Mario

Tags

cash flows; genetic algorithm; meta-heuristic; net present value; project management; resource constrained project scheduling

Reference

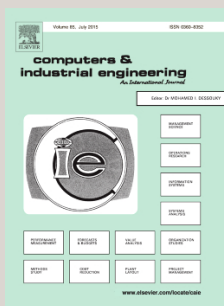
Leyman, P. and Vanhoucke, M. (2015). Payment models and net present value optimization for resource-constrained project scheduling. *Computers and Industrial Engineering*, 91:139–153

DOI

10.1016/j.cie.2015.11.008

Classification

International peer-reviewed journal; Written for researchers; Data and solutions available at www.projectmanagement.ugent.be



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Payment models

This manuscript focuses on the single- and multi-mode resource-constrained project scheduling problem with discounted cash flows (RCPSPDC and MRCPSPPDC) and three payment models. The contribution of the paper is twofold. First, we extend a new scheduling technique, which moves activities in order to improve the project net present value. This more general version is applicable to multiple problem formulations and provides an overarching framework in which these models can be implemented. The changes in activity finish times take other activities and the possible changes in the finish times of these other activities into account, by forming a set of activities which is subsequently moved in time. The scheduling technique is implemented within a genetic algorithm metaheuristic and employs two penalty functions, one for deadline feasibility and one for nonrenewable resource feasibility. Second, we test the proposed approach on several datasets from literature and illustrate the added value of each part of the algorithm. The influence of data parameters on the project net present value is highlighted. The detailed results provided in this paper can be used as future benchmarks for each of the six models discussed.

The payment for sins can be delayed. But they can't be avoided.
Shawn Ryan



A new solution approach to solve the resource-constrained project scheduling problem with logical constraints

Vanhoucke, Mario; Coelho, José

Tags

boolean satisfiability problem;
genetic algorithm; meta-
heuristic; project management;
resource constrained project
scheduling

Reference

Vanhoucke, M. and Coelho, J.
(2016). A new solution approach
to solve the resource-constrained
project scheduling problem with
logical constraints. *European
Journal of Operational Research*,
249:577–591

DOI

10.1016/j.ejor.2015.08.044

Classification

International peer-reviewed jour-
nal; Written for researchers; Data
and solutions available at [www.
projectmanagement.ugent.be](http://www.projectmanagement.ugent.be)



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Logical constraints

This paper presents a new solution approach to solve the resource-constrained project scheduling problem in the presence of three types of logical constraints. Apart from the traditional AND constraints with minimal time-lags, these precedences are extended to OR constraints and bidirectional (BI) relations. These logical constraints extend the set of relations between pairs of activities and make the RCPSP definition somewhat different from the traditional RCPSP research topics in literature. It is known that the RCPSP with AND constraints, and hence its extension to OR and BI constraints, is NP-hard. The new algorithm consists of a set of network transformation rules that removes the OR and BI logical constraints to transform them into AND constraints and hereby extends the set of activities to maintain the original logic. A satisfiability (SAT) solver is used to guarantee the original precedence logic and is embedded in a metaheuristic search to resource feasible schedules that respect both the limited renewable resource availability as well as the precedence logic. Computational results on two well-known datasets from literature show that the algorithm can compete with the multi-mode algorithms from literature when no logical constraints are taken into account. When the logical constraints are taken into account, the algorithm can report major reductions in the project makespan for most of the instances within a reasonable time.

*Logic will get you from A to B.
Imagination will take you
everywhere.*
Albert Einstein



A comparative study of Artificial Intelligence methods for project duration forecasting

Wauters, Mathieu; Vanhoucke, Mario

Tags

artificial intelligence; earned schedule; earned value management; forecasting; project control; project management; simulation

Reference

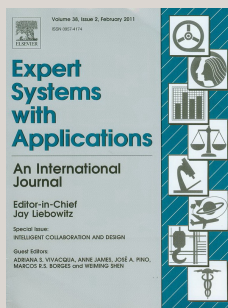
Wauters, M. and Vanhoucke, M. (2016). A comparative study of artificial intelligence methods for project duration forecasting. *Expert Systems with Applications*, 46:249–261

DOI

10.1016/j.eswa.2015.10.008

Classification

International peer-reviewed journal; Written for researchers; R files available at www.projectmanagement.ugent.be



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Artificial intelligence

This paper presents five Artificial Intelligence (AI) methods to predict the final duration of a project. A methodology that involves Monte Carlo simulation, Principal Component Analysis and cross-validation is proposed and can be applied by academics and practitioners. The performance of the AI methods is assessed by means of a large and topologically diverse dataset and is benchmarked against the best performing Earned Value Management/Earned Schedule (EVM/ES) methods. The results show that the AI methods outperform the EVM/ES methods if the training and test sets are at least similar to one another. Additionally, the AI methods report excellent early and mid-stage forecasting results. A robustness experiment gradually increases the discrepancy between the training and test sets and demonstrates the limitations of the newly proposed AI methods.

By far the greatest danger of Artificial Intelligence is that people conclude too early that they understand it.
Eliezer Yudkowsky



An overview of project data for integrated project management and control

Vanhoucke, Mario, Coelho, José; Batselier, Jordy

Tags

project management; project data;

Reference

Vanhoucke, M. (2016). An overview of project data for integrated project management and control. *Journal of Modern Project Management*, 3(2):6–21

URL

www.journalmodernpm.com

Classification

International peer-reviewed journal; Written for researchers and professionals; Project data is available at www.projectmanagement.ugent.be



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Big data

In this paper, an overview is given of the project data instances available in the literature to carry out academic research in the field of integrated project management and control. This research field aims at integrating static planning methods and risk analyses with dynamic project control methodologies using the state-of-the-art knowledge from literature and the best practices from the professional project management discipline. Various subtopics of this challenging discipline have been investigated from different angles, each time using project data available in literature, obtained from project data generators or based on a sample of empirical case studies. This paper gives an overall overview of the wide variety of project data that are available and are used in various research publications. It will be shown how the combination of artificial data and empirical data leads to improved knowledge on and deeper insights into the structure and characteristics of projects useful for academic research and professional use. While the artificial data can be best used to test novel ideas under a strict design in a controlled academic environment, empirical data can serve as the necessary validation step to translate the academic research results into practical ideas, aiming at narrowing the bridge between the theoretical knowledge and practical relevance. A summary of the available project data discussed in this paper can be downloaded from www.projectmanagement.ugent.be/research/data.

*It is a capital mistake to theorize
before one has data.
Arthur Conan Doyle*



Construction and evaluation framework for a real-life project database

Batselier, Jordy; Vanhoucke, Mario

Tags

dynamic scheduling; earned schedule; earned value management; empirical data; project management

Reference

Batselier, J. and Vanhoucke, M. (2015). Construction and evaluation framework for a real-life project database. *International Journal of Project Management*, 33:697–710

DOI

10.1016/j.ijproman.2014.09.004

Classification

International peer-reviewed journal; Written for researchers and professionals; Empirical project data available at www.projectmanagement.ugent.be



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Empirical database

In this paper, a real-life project database is created, outranking the existing empirical databases from project management literature in both size and diversity. To ensure the quality of the added project data, a database construction and evaluation framework based on the so-called project cards is developed. These project cards incorporate the concepts of dynamic scheduling and introduce two novel evaluation measures for the authenticity of project data. Furthermore, an overview of the constructed database leads to statements on the difference between planned and actual project performance and on the earned value management (EVM) forecasting accuracy. Moreover, the database is publicly available and can thus become the basis for many future studies related to project management, of which a few are suggested in this paper. To further support these studies, the database will continuously be extended utilizing the project cards. Furthermore, the project cards can also serve didactical purposes.

No one undertakes research in physics with the intention of winning a prize. It is the joy of discovering something no one knew before.
Stephen Hawking



Empirical evaluation of earned value management forecasting accuracy for time and cost

Batselier, Jordy; Vanhoucke, Mario

Tags

earned schedule; earned value management; empirical data; forecasting; project management

Reference

Batselier, J. and Vanhoucke, M. (2015). Empirical evaluation of earned value management forecasting accuracy for time and cost. *Journal of Construction Engineering and Management*, 141(11):1–13

DOI

10.1061/(ASCE)CO.1943-7862.0001008

Classification

International peer-reviewed journal; Written for researchers and professionals



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Empirical evaluation

The ability to accurately forecast a project's final duration and cost is essential to successful project management. The technique of earned value management (EVM) is considered to provide an effective methodology for obtaining such forecasts; however, this has not yet been adequately tested on empirical data. Therefore, the accuracy of the most commonly used EVM time and cost forecasting methods is evaluated on a diverse and qualitative database consisting of 51 real-life projects. As most projects originate from the construction industry, an explicit focus on these construction projects is provided. Moreover, the desired real forecasting outcomes based on the actual project progress data are also supported by a Monte Carlo simulation study. It is demonstrated that highly accurate time and cost forecasts can be obtained by applying the EVM methodology. Furthermore, the best performing forecasting methods for the projects in the considered database are identified, also taking into account timeliness and the influence of the project network structure.

*No one has the right to destroy
another person's belief by
demanding empirical evidence.*
Ann Landers



Evaluation of deterministic state-of-the-art forecasting approaches for project duration based on earned value management

Batselier, Jordy; Vanhoucke, Mario

Tags

earned schedule; earned value management; empirical data; forecasting; project management

Reference

Batselier, J. and Vanhoucke, M. (2015). Evaluation of deterministic state-of-the-art forecasting approaches for project duration based on earned value management. *International Journal of Project Management*, 33:1588–1596

DOI

10.1016/j.ijproman.2015.04.003

Classification

International peer-reviewed journal; Written for researchers and professionals



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State-of-the-art forecasting

In recent years, a variety of novel approaches for fulfilling the important management task of accurately forecasting project duration have been proposed, with many of them based on the earned value management (EVM) methodology. However, these state-of-the-art approaches have often not been adequately tested on a large database, nor has their validity been empirically proven. Therefore, we evaluate the accuracy and timeliness of three promising deterministic techniques and their mutual combinations on a real-life project database. More specifically, two techniques respectively integrate rework and activity sensitivity in EVM time forecasting as extensions, while a third innovatively calculates schedule performance from time-based metrics and is appropriately called earned duration management or EDM(t). The results indicate that all three of the considered techniques are relevant. More concretely, the two EVM extensions exhibit accuracy-enhancing power for different applications, while EDM(t) performs very similar to the best EVM methods and shows potential to improve them.

*Progress lies not in enhancing
what is, but in advancing towards
what will be.*
Khalil Gibran



On the design of custom packs: Grouping of medical disposable items for surgeries

Cardoen, Brecht; Beliën, Jeroen; Vanhoucke, Mario

Tags

case study; healthcare scheduling; linear programming; simulated annealing

Reference

Cardoen, B., Beliën, J., and Vanhoucke, M. (2015). On the design of custom packs: Grouping of medical disposable items for surgeries. *International Journal of Production Research*, 53:7343–7359

DOI

10.1080/00207543.2015.1061221

Classification

International peer-reviewed journal; Written for researchers and professionals



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Custom packs design

A custom pack combines medical disposable items into a single sterile package that is used for surgical procedures. Although custom packs are gaining importance in hospitals due to their potential benefits in reducing surgery setup times, little is known on methodologies to configure them, especially if the number of medical items, procedure types and surgeons is large. In this paper, we propose a mathematical programming approach to guide hospitals in developing or reconfiguring their custom packs. In particular, we are interested in minimising points of touch, which we define as a measure for physical contact between staff and medical materials. Starting from an integer non-linear programming model, we develop both an exact linear programming (LP) solution approach and an LP-based heuristic. Next, we also describe a simulated annealing approach to benchmark the mathematical programming methods. A computational experiment, based on real data of a medium-sized Belgian hospital, compares the optimised results with the performance of the hospital's current configuration settings and indicates how to improve future usage. Next to this base case, we introduce scenarios in which we examine to what extent the results are sensitive for waste, i.e. adding more items to the custom pack than is technically required for some of the custom pack's procedures, since this can increase its applicability towards other procedures. We point at some interesting insights that can be taken up by the hospital management to guide the configuration and accompanying negotiation processes.

Poetic knowledge is born in the
great silence of scientific
knowledge.
Aime Cesaire



A comparison of the performance of various project control methods using earned value management systems

Colin, Jeroen; Vanhoucke, Mario

Tags

critical chain/buffer management; earned schedule; earned value management; project management; schedule risk analysis; simulation; statistical project control

Reference

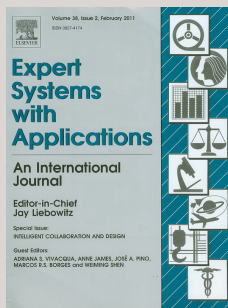
Colin, J. and Vanhoucke, M. (2015). A comparison of the performance of various project control methods using earned value management systems. *Expert Systems with Applications*, 42:3159–3175

DOI

10.1016/j.eswa.2014.12.007

Classification

International peer-reviewed journal; Written for researchers



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Comparing control methods

Recent literature on project management has emphasised the effort which is spent by the management team during the project control process. Based on this effort, a functional distinction can be made between a top down and a bottom up project control approach. A top down control approach refers to the use of a project control system that generates project based performance metrics to give a general overview of the project performance. Actions are triggered based on these general performance metrics, which need further investigation to detect problems at the activity level. A bottom up project control system refers to a system in which detailed activity information needs to be available constantly during the project control process, which requires more effort. In this research, we propose two new project control approaches, which combines elements of both top down and bottom up control. To this end, we integrate the earned value management/earned schedule (EVM/ES) method with multiple control points inspired by critical chain/buffer management (CC/BM). We show how the EVM/ES control approach is complementary with the concept of buffers and how they can improve the project control process when cleverly combined. These combined top down approaches overcome some of the drawbacks of traditional EVM/ES mentioned in the literature, while minimally increasing the effort spent by the project manager. A large computational experiment is set up to test the approach against other control procedures within a broad range of simulated dynamic project progress situations.

The price of inaction is far greater than the cost of making a mistake.
Meister Eckhart



Empirical perspective on activity durations for project management simulation studies

Colin, Jeroen; Vanhoucke, Mario

Tags

empirical data; lognormal core;
project management; simulation

Reference

Colin, J. and Vanhoucke, M. (2015). Empirical perspective on activity durations for project management simulation studies. *Journal of Construction Engineering and Management*, 04015047:1–13

DOI

10.1061/(ASCE)CO.1943-7862.0001022

Classification

International peer-reviewed journal; Written for researchers and professionals; R files available at www.projectmanagement.ugent.be



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Empirical distributions

Simulation has played an important role in project-management studies of the last decades, but in order for them to produce practical results, a realistic distribution model for activity durations is indispensable. The construction industry often has needed historical records of project executions, to serve as inputs to the distribution models, but a clearly outlined calibration procedure is not always readily available, nor are their results readily interpretable. This study seeks to illustrate how data from the construction industry can be used to derive realistic input distributions. Therefore, the Parkinson simulation model with a lognormal core is applied to a large empirical dataset from the literature and the results are described. From a discussion of these results, an empirical classification of project executions is presented. Three possible uses are presented for the calibration procedure and the classification in project management simulation studies. These were validated using a case study of a construction company.

*Learning by doing, peer-to-peer
teaching, and computer
simulation are all part of the
same equation.*
Nicholas Negroponte



Developing a framework for statistical process control approaches in project management

Colin, Jeroen; Vanhoucke, Mario

Tags

control charts; earned schedule;
earned value management;
project management; simulation;
statistical project control

Reference

Colin, J. and Vanhoucke, M.
(2015). Developing a framework
for statistical process control ap-
proaches in project management.
*International Journal of Project
Management*, 33(6):1289–1300

DOI

10.1016/j.ijproman.2015.03.014

Classification

International peer-reviewed jour-
nal; Written for researchers and
professionals



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Statistical project control

Different statistical process control (SPC) approaches were proposed over the years for project management using earned value management/ earned schedule. A detailed examination of these approaches has led us to express a need for a unified framework in which to test and compare them. The main drivers for this need were the lack of a formal definition for a state of control, the unavailability of a benchmark dataset, the absence of measures to quantify the SPC performance and the lack of consensus on how to overcome and test the normality assumption. In this paper, we present such a framework that combines a classification from empirical data, a known project dataset, a sound simulation model and two quantitative measures for project control efficiency. Four SPC approaches from prior literature have been implemented and an exhaustive experiment was set up to compare and to discuss their value for the project management practice.

*Data is a precious thing and will
last longer than the systems
themselves.*
Tim Berners-Lee



A multivariate approach to top down project control using earned value management

Colin, Jeroen; Martens, Annelies; Vanhoucke, Mario; Wauters, Mathieu

Tags

earned schedule; earned value management; multivariate statistics; principal component analysis; project management; simulation; statistical project control

Reference

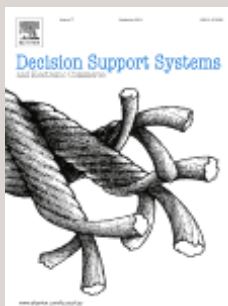
Colin, J., Martens, A., Vanhoucke, M., and Wauters, M. (2015). A multivariate approach to top down project control using earned value management. *Decision Support Systems*, 79:65–76

DOI

10.1016/j.dss.2015.08.002

Classification

International peer-reviewed journal; Written for researchers; Appendices available at www.projectmanagement.ugent.be



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Multivariate project control

Project monitoring and the related decision to proceed to corrective action are crucial components of an integrated project management and control Decision Support System (DSS). Earned Value Management/Earned Schedule (EVM/ES) is a project control methodology that is typically applied for top-down project schedule control. However, traditional models do not correctly account for the multivariate nature of the EVM/ES measurement system. We therefore propose a multivariate model for EVM/ES, which implements a Principal Component Analysis (PCA) on a simulated schedule control reference. During project progress, the real EVM/ES observations can then be projected onto these principal components. This allows for two new multivariate schedule control metrics (T2 and SPE) to be calculated, which can be dynamically monitored on project control charts. Using a computational experiment, we show that these multivariate schedule control metrics lead to performance improvements and practical advantages in comparison with traditional univariate EVM/ES models.

In ancient times they had no statistics so they had to fall back on lies.
Stephen Leacock



A new scheduling technique for the resource-constrained project scheduling problem with discounted cash flows

Leyman, Pieter; Vanhoucke, Mario

Tags

cash flows; genetic algorithm; meta-heuristic; net present value; project management; resource constrained project scheduling

Reference

Leyman, P. and Vanhoucke, M. (2015). A new scheduling technique for the resource-constrained project scheduling problem with discounted cash flows. *International Journal of Production Research*, 53:2771–2786

DOI

10.1080/00207543.2014.980463

Classification

International peer-reviewed journal; Written for researchers; Data and solutions available at www.projectmanagement.ugent.be



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Cash flow models

In this paper, we discuss the resource-constrained project scheduling problem with discounted cash flows. We introduce a new schedule construction technique which moves sets of activities to improve the project net present value and consists of two steps. In particular, the inclusion of individual activities into sets, which are then moved together, is crucial in both steps. The first step groups the activities based on the predecessors and successors in the project network, and adds these activities to a set based on their finish time and cash flow. The second step on the contrary does so based on the neighbouring activities in the schedule, which may but need not include precedence related activities. The proposed scheduling method is implemented in a genetic algorithm metaheuristic and we employ a penalty function to improve the algorithm's feasibility with respect to a tight deadline. All steps of the proposed solution methodology are tested in detail and an extensive computational experiment shows that our results are competitive with existing work.

Yesterday is a cancelled check.
Today is cash on the line.
Tomorrow is a promissory note.
Hank Stram



An exact algorithm for an integrated project staffing problem with a homogeneous workforce

Maenhout, Broos; Vanhoucke, Mario

Tags

branch-and-price; project management; project scheduling; project staffing; resource analysis

Reference

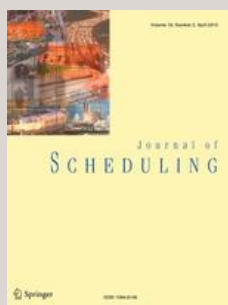
Maenhout, B. and Vanhoucke, M. (2015). An exact algorithm for an integrated project staffing problem with a homogeneous workforce. *Journal of Scheduling*, To Appear

DOI

10.1007/s10951-015-0443-z

Classification

International peer-reviewed journal; Written for researchers



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Homogeneous workforce

When scheduling projects under resource constraints, assumptions are typically made with respect to the resource availability. In resource scheduling problems important assumptions are made with respect to the resource requirements. As projects are typically labour intensive, the underlying (personnel) resource scheduling problems tend to be complex due to different rules and regulations. In this paper, we aim to integrate these two interrelated scheduling problems to minimise the overall cost. For that purpose, we propose an exact algorithm for the project staffing with resource scheduling constraints. Detailed computational experiments are presented to evaluate different branching rules and pruning strategies and to compare the proposed procedure with other optimisation techniques.

*To succeed you have to believe in
something with such a passion
that it becomes a reality.*
Dame Anita Roddick



A resource type analysis of the integrated project scheduling and personnel staffing problem

Maenhout, Broos; Vanhoucke, Mario

Tags

project management; project staffing; resource analysis

Reference

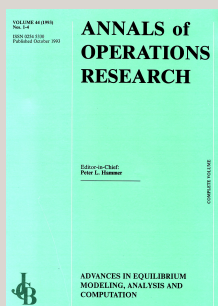
Maenhout, B. and Vanhoucke, M. (2015). A resource type analysis of the integrated project scheduling and personnel staffing problem. *Annals of Operations Research*, To Appear

DOI

10.1007/s10479-015-2033-z

Classification

International peer-reviewed journal; Written for researchers

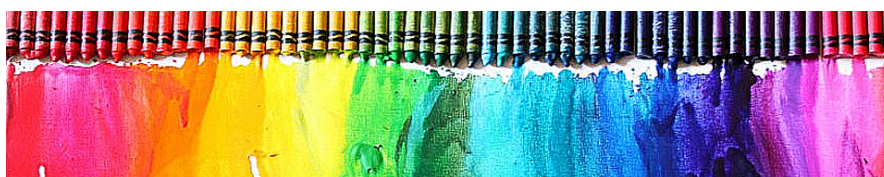


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Scheduling & Staffing

In the integrated project scheduling and personnel staffing problem the project activities are scheduled and simultaneously a staffing plan is composed to carry out a single project. In this way, the project schedule that leads to the staffing plan with minimum cost is determined. In this paper, we evaluate different scheduling policies and practices for different personnel resource types. We examine the impact on the staffing cost when the personnel resources are scheduled in a cyclic versus a non-cyclic manner for different (days on, days off)-patterns. Furthermore, the impact of introducing more flexible resource types, such as overtime and temporary help, is explored in relationship with the activity resource demand variability. Computational results show that non-cyclic scheduling leads to a considerable lower staffing cost under all circumstances compared to cyclic scheduling. However, despite the tractability of the resource requirements, flexible temporary resources are essential on top of the regular personnel resources to respond to the variability in demand. The addition of overtime on a strategic staffing level only marginally decreases the personnel cost.

*There's no such thing as a mistake,
really. It's just an opportunity to
do something else.*
Ralph Steadman



Hybrid tabu search and a truncated branch-and-bound for the unrelated parallel machine scheduling problem

Sels, Veronique; Coelho, José; Dias, António Manuel; Vanhoucke, Mario

Tags

boolean satisfiability problem;
branch-and-bound; meta-
heuristic; parallel machine
scheduling; production
scheduling; tabu search

Reference

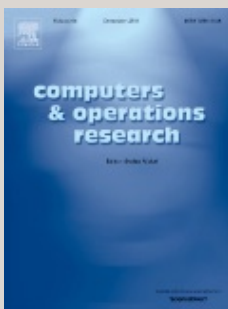
Sels, V., Coelho, J., Dias, A., and Vanhoucke, M. (2014). Hybrid tabu search and a truncated branch-and-bound for the unrelated parallel machine scheduling problem. *Computers & Operations Research*, 53:107–117

DOI

10.1016/j.cor.2014.08.002

Classification

International peer-reviewed journal;
Written for researchers



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Unrelated machines

We consider the problem of scheduling a number of jobs on a number of unrelated parallel machines in order to minimize the makespan. We develop three heuristic approaches, i.e., a genetic algorithm, a tabu search algorithm and a hybridization of these heuristics with a truncated branch-and-bound procedure. This hybridization is made in order to accelerate the search process to near-optimal solutions. The branch-and-bound procedure will check whether the solutions obtained by the meta-heuristics can be scheduled within a tight upper bound. We compare the performances of these heuristics on a standard dataset available in the literature. Moreover, the influence of the different heuristic parameters is examined as well. The computational experiments reveal that the hybrid heuristics are able to compete with the best known results from the literature.

*An algorithm must be seen to be
believed.*
Donald Knuth



A scatter search for the extended resource renting problem

Vandenheede, Len; Vanhoucke, Mario; Maenhout, Broos

Tags

meta-heuristic; project management; project scheduling; resource renting problem; scatter search

Reference

Vandenheede, L., Vanhoucke, M., and Maenhout, B. (2015). A scatter search for the extended resource renting problem. *International Journal of Production Research*, To Appear

DOI

10.1080/00207543.2015.1064177

Classification

International peer-reviewed journal; Written for researchers



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Resource renting

In this paper, the extended Resource Renting Problem (RRP/extended) is presented. The RRP/extended is a time-constrained project scheduling problem, in which the total project cost is minimised. In the RRP/extended, this total project cost is determined by a number of extra costs, which are defined in this paper. These costs are based on the costs that are used in the traditional Resource Renting Problem and the Total Adjustment Cost Problem. Therefore, the RRP/extended represents a union of these two problems. To solve the RRP/extended, a scatter search is developed. The building blocks of this scatter search are specifically designed for the RRP/extended. We introduce two crossovers and an improvement method. The efficiency of these building blocks will be shown in the paper. Furthermore, a sensitivity analysis is presented in which the five costs have diverse values.

The characteristic of scientific progress is our knowing that we did not know.
Gaston Bachelard



Operating theatre modelling: integrating social measures

Van Huele, Christophe; Vanhoucke, Mario

Tags

healthcare scheduling; operation room scheduling; personnel scheduling; simulation

Reference

Van Heule, C. and Vanhoucke, M. (2015). Operating theatre modelling: integrating social measures. *Journal of Simulation*, 9:121–128

DOI

10.1057/jos.2014.32

Classification

International peer-reviewed journal; Written for researchers



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Operating theatre

Hospital resource modelling literature is primarily focussed on productivity and efficiency measures. In this paper, our focus is on the alignment of the most valuable revenue factor, the operating room (OR) with the most valuable cost factor, the staff. When aligning these economic and social decisions, respectively, into one sustainable model, simulation results justify the integration of these factors. This research shows that integrating staff decisions and OR decisions results in better solutions for both entities. A discrete event simulation approach is used as a performance test to evaluate an integrated and an iterative model. Experimental analysis show how our integrated approach can benefit the alignment of the planning of the human resources as well as the planning of the capacity of the OR based on both economic related metrics (lead time, overtime, number of patients rejected) and social related metrics (personnel preferences, aversions, roster quality).

*Programming is modellisation of
real life.*
Fode Toure



On the use of multivariate regression methods for longest path calculations from earned value management observations

Vanhoucke, Mario; Colin, Jeroen

Tags

earned schedule; earned value management; multivariate statistics; project management; simulation; statistical project control

Reference

Vanhoucke, M. and Colin, J. (2015). On the use of multivariate regression methods for longest path calculations from earned value management observations. *Omega The International Journal of Management Science*, page To Appear

DOI

10.1016/j.omega.2015.07.013

Classification

International peer-reviewed journal; Written for researchers and professionals



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Multivariate regression

This paper explores the use of multivariate regression methods for project schedule control, within a statistical project control framework (Colin and Vanhoucke 2014). These multivariate regression methods monitor the activity level performance of an ongoing project from the earned value management/earned schedule (EVM/ES) observations that are made at a high level of the work breakdown structure (WBS). These estimates can be used to calculate the longest path in the project and to produce warning signals for project schedule control. The effort that is spent by the project manager is thereby reduced, since a drill-down of the WBS is no longer required for every review period. An extensive computational experiment was set up to test and compare four distinct multivariate regression methods on a database of project networks. The kernel principal component regression method, when used with a radial base function kernel, was found to outperform the other presented regression methods.

*I think statistics go in one ear and
out the other. All of us respond to
stories more than numbers.*

Koren Zailckas



Influence of learning in resource-constrained project scheduling

Van Peteghem, Vincent; Vanhoucke, Mario

Tags

discrete time/resource trade-off;
genetic algorithm; learning;
meta-heuristic; project man-
agement; resource constrained
project scheduling

Reference

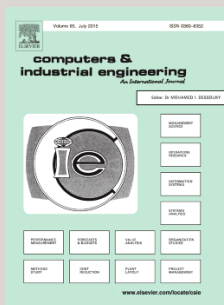
Van Peteghem, V. and Van-
houcke, M. (2015). Influence of
learning in resource-constrained
project scheduling. *Comput-
ers and Industrial Engineering*,
87:569–579

DOI

10.1016/j.cie.2015.06.007

Classification

International peer-reviewed jour-
nal; Written for researchers and
professionals



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Learning in projects

Learning effects assume that the efficiency of a resource increases with the duration of a task. Although these effects are commonly used in machine scheduling environments, they are rarely used in a project scheduling setting. In this paper, the effect of learning in a project scheduling environment is studied and applied to the discrete time/resource trade-off scheduling problem (DTRTP), where each activity has a fixed work content for which a set of execution modes (duration/resource requirement pairs) can be defined. Computational results emphasize the significant impact of learning effects on the project schedule, measure the margin of error made by ignoring learning and show that timely incorporation of learning effects can lead to significant makespan improvements.

*You have to learn the rules of the
game. And then you have to play
better than anyone else.*
Albert Einstein



A study of the stability of Earned Value Management forecasting

Wauters, Mathieu; Vanhoucke, Mario

Tags

artificial intelligence; earned schedule; earned value management; forecasting; project control; project management; simulation; support vector machines

Reference

Wauters, M. and Vanhoucke, M. (2015). A study of the stability of earned value management forecasting. *Journal of Construction Engineering and Management*, 141(4):1–10

DOI

10.1061/(ASCE)CO.1943-7862.0000947

Classification

International peer-reviewed journal; Written for researchers



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Earned value stability

In this paper, the authors focus on the stability of earned value management (EVM) forecasting methods. The contribution is threefold. First of all, a new criterion to measure stability that does not suffer from the disadvantages of the historically employed concept is proposed. Second, the stability of time and cost forecasting methods is compared and contrasted by means of a computational experiment on a topologically diverse data set. Throughout these experiments, the forecasting accuracy is reported as well, facilitating a trade-off between accuracy and stability. Finally, it is shown that the novel stability metric can be used in practical environments using two real-life projects. The conclusions of this empirical validation are found to be largely in line with the computational results.

Flexibility has become a modern day value that everyone wants. But flexibility comes with a cost.
Maynard Webb



Classification of articles and journals on project control and earned value management

Willems, Laura; Vanhoucke, Mario

Tags

earned schedule; earned value management; literature review; project control; project management

Reference

Willems, L. and Vanhoucke, M. (2015). Classification of articles and journals on project control and earned value management. *International Journal of Project Management*, 33:1610–1634

DOI

10.1016/j.ijproman.2015.06.003

Classification

International peer-reviewed journal; Written for researchers and professionals



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Journal classification

This paper presents an overview of the existing literature on project control and earned value management (EVM), aiming at fulfilling three ambitions. First, the journal selection procedure allows to discern between high-quality journals and more popular business magazines. Second, the collected papers on project control and EVM, published in the selected journals, are classified based on a framework consisting of six distinct classes. Third, the classification framework indicates current trends and potential areas for future research, which can be summarized as follows: (i) increased attention to the stochastic nature of projects, (ii) enhanced validation of the proposed methodology using a large historical dataset or a simulation experiment, (iii) expansion of integrated control models, focusing on time and cost as well as other factors such as quality and sustainability, and (iv) development and validation of corrective action procedures.

To get to know, to discover, to publish. This is the destiny of a scientist.
François Arago



Controlling projects

Vanhoucke, Mario

Tags

earned schedule; earned value management; project control; project management

Reference

Vanhoucke, M. (2015). Controlling projects. *Journal of Modern Project Management*, 3:5–5

URL

www.journalmodernpm.com

Classification

International peer-reviewed journal; Written for researchers and professionals



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Project control

Completing a project on time and within budget is not an easy task. Project monitoring and controlling systems should consist of processes that are performed to observe project progress in such a way that potential problems can be identified in a timely manner. When necessary, corrective actions can be taken to exploit project opportunities or to bring projects in danger back on track. The requisite is that project performance is observed and measured regularly to identify deviations from the project baseline schedule. Therefore, monitoring the progress and performance of projects in progress requires a set of tools and techniques that should ideally be integrated into a single decision support system. The understanding of the basic elements and concepts is a requisite to successfully use and implement the various project control concepts in an integrated project management and control system.

*If everything seems under control,
you're not going fast enough.*
Mario Andretti



On the use of Schedule Risk Analysis for Project Management

Vanhoucke, Mario

Tags

project management; schedule risk analysis

Reference

Vanhoucke, M. (2015). On the use of schedule risk analysis for project management. *Journal of Modern Project Management*, 2(3):108–117

URL

www.journalmodernpm.com

Classification

International peer-reviewed journal; Written for researchers and professionals



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Schedule risk analysis

The purpose of this paper is to give an overview on the existing literature and recent developments on the research on Schedule Risk Analysis (SRA) in Project Management (PM) to measure the sensitivity of activities and resources in the project network. SRA is a technique that relies on Monte-Carlo simulation runs to analyze the impact of changes in activity durations and costs on the overall project time and cost objectives. First, the paper gives an overview of the most commonly known sensitivity metrics from literature that are widely used by PM software tools to measure the time and cost sensitivity of activities as well as sensitivity for project resources. Second, the relevance of these metrics in an integrated project control setting is discussed based on some recent research studies. Finally, a short discussion on the challenges for future research is given. All sections in this paper are based on research studies done in the past for which references will be given throughout the manuscript.

If anything is certain, it is that change is certain. The world we are planning for today will not exist in this form tomorrow.
Phil Crosby



Decomposition-based heuristics for the integrated physician rostering and surgery scheduling problem

Van Huele, Christophe; Vanhoucke, Mario

Tags

healthcare scheduling; heuristics; physician scheduling; surgery scheduling

Reference

Van Heule, C. and Vanhoucke, M. (2015). Decomposition-based heuristics for the integrated physician rostering and surgery scheduling problem. *Journal of Health Systems*, 4:159–175

DOI

10.1057/hs.2014.27

Classification

International peer-reviewed journal; Written for researchers



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Decomposition heuristic

In this paper, a comparison and validation of various priority rules for the Integrated Physician Rostering and Surgery Scheduling Problem (IPSSP) under different objective functions is made. We integrate three constructive heuristic types with two corresponding priority rule classes in order to obtain a solution for the combined physician rostering and surgery scheduling problem. Twelve priority rules for the surgery assignments and six priority rules for the physician rostering are used to schedule the surgeries in the operating theatre on a weekly basis, while generating adequate rosters for the physicians that maximizes their preferences. Our goal is to provide a suitable heuristic for every problem type, problem size and problem structure for the hospital manager to use in every possible condition. The problem type represents the most occurring objectives and goals according to literature. The problem size depicts the size of the hospital and its corresponding utilization. The problem structure defines the different demands of the physician roster and the surgery schedule. It can be shown that for every situation a fitting heuristic can be provided. These high-quality decomposition-based constructive heuristics can also be used in meta-heuristics to generate good solutions. Most importantly, we have established general recommendations with respect to the use of the different proposed heuristics in different hospital settings.

Order and simplification are the first steps toward the mastery of a subject.
Thomas Mann



Setting tolerance limits for statistical project control Using Earned Value Management

Colin, Jeroen; Vanhoucke, Mario

Tags

control charts; earned schedule;
earned value management;
project management; simulation;
statistical project control

Reference

Colin, J. and Vanhoucke, M.
(2014). Setting tolerance limits
for statistical project control us-
ing earned value management.
*Omega The International Journal
of Management Science*, 49:107–
122

DOI

10.1016/j.omega.2014.06.001

Classification

International peer-reviewed jour-
nal; Written for researchers



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Control tolerance limits

Project control has been a research topic since decades that attracts both academics and practitioners. Project control systems indicate the direction of change in preliminary planning variables compared with actual performance. In case their current project performance deviates from the planned performance, a warning is indicated by the system in order to take corrective actions. Earned value management/earned schedule (EVM/ES) systems have played a central role in project control, and provide straightforward key performance metrics that measure the deviations between planned and actual performance in terms of time and cost. In this paper, a new statistical project control procedure sets tolerance limits to improve the discriminative power between progress situations that are either statistically likely or less likely to occur under the project baseline schedule. In this research, the tolerance limits are derived from subjective estimates for the activity durations of the project. Using the existing and commonly known EVM/ES metrics, the resulting project control charts will have an improved ability to trigger actions when variation in a project's progress exceeds certain predefined thresholds. A computational experiment has been set up to test the ability of these statistical project control charts to discriminate between variations that are either acceptable or unacceptable in the duration of the individual activities. The computational experiments compare the use of statistical tolerance limits with traditional earned value management thresholds and validate their power to report warning signals when projects tend to deviate significantly from the baseline schedule.

*Facts are stubborn, but statistics
are more pliable.*
Mark Twain



Scheduling of unrelated parallel machines with limited server availability on multiple production locations: a case study in knitted fabrics

Kerkhove, Louis-Philippe; Vanhoucke, Mario

Tags

case study; genetic algorithm; meta-heuristic; parallel machine scheduling; production scheduling; sequence-dependent setup times

Reference

Kerkhove, L. and Vanhoucke, M. (2014). Scheduling of unrelated parallel machines with limited server availability on multiple production locations: a case study in knitted fabrics. *International Journal of Production Research*, 52:2630–2653

DOI

10.1080/00207543.2013.865855

Classification

International peer-reviewed journal; Written for researchers



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Knitted fabrics

This paper studies a complex variation of the parallel machine scheduling (PMS) problem, as encountered at a Belgian producer of knitted fabrics. The aim is to assign N_J jobs to N_M unrelated parallel machines, minimising a weighted combination of job lateness and tardiness. Jobs are assigned specific release, and due dates and changeover times are sequence dependent. Current literature is extended by including geographically dispersed production locations, which influence job due dates and objective function coefficients. Furthermore, the changeover interference due to limited availability of technicians is also studied in this paper. The scheduling problem is solved using a hybrid meta-heuristic, which combines elements from simulated annealing and genetic algorithms. This hybrid meta-heuristic is capable of solving real-scale scheduling problems of up to 750 jobs, 75 machines and 10 production locations within reasonable computation time. This hybrid scheduling procedure is extended with heuristic dispatching rules capable of reducing the impact of changeover interference by 23% on average compared to the random scenario, for the case where a single technician is expected to serve up to 12 machines.

*There cannot be a crisis next week.
My schedule is already full.*
Henry A. Kissinger



A hybrid Electromagnetism-like Mechanism/tabu search procedure for the single machine scheduling problem with a maximum lateness objective

Sels, Veronique; Vanhoucke, Mario

Tags

electromagnetism; meta-heuristic; production scheduling; single machine scheduling; tabu search

Reference

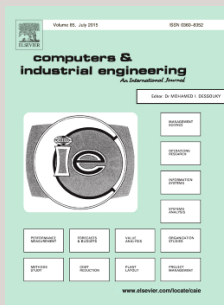
Sels, V. and Vanhoucke, M. (2014). A hybrid electromagnetism-like mechanism/tabu search procedure for the single machine scheduling problem with a maximum lateness objective. *Computers and Industrial Engineering*, 67:44–55

DOI

10.1016/j.cie.2013.10.013

Classification

International peer-reviewed journal; Written for researchers; Data and solutions available at www.projectmanagement.ugent.be



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Hybrid machine scheduling

This paper presents a hybrid meta-heuristic search procedure to solve the well-known single machine scheduling problem to minimize the maximum lateness over all jobs, where precedence relations may exist between some of the jobs. The hybridization consists of a well-designed balance between the principles borrowed from an Electromagnetism-like Mechanism algorithm and the characteristics used in a tabu search procedure. The Electromagnetism-like Mechanism (EM) algorithm follows a search pattern based on the theory of physics to simulate attraction and repulsion of solutions in order to move towards more promising solutions. The well-known tabu search enhances the performance of a local search method by using memory structures by prohibiting visited solutions during a certain time of the search process. The hybridization of both algorithms results in an important trade-off between intensification and diversification strategies. These strategies will be discussed in detail. To that purpose, a new set of data instances is used to compare different elements of the hybrid search procedure and to validate the performance of the algorithm.

*By denying scientific principles,
one may maintain any paradox.
Galileo Galilei*



Analysis of the integration of the physician rostering problem and the surgery scheduling problem

Van Huele, Christophe; Vanhoucke, Mario

Tags

healthcare scheduling; linear programming; physician scheduling; surgery scheduling

Reference

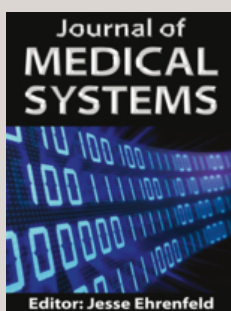
Van Heule, C. and Vanhoucke, M. (2014). Analysis of the integration of the physician rostering problem and the surgery scheduling problem. *Journal of Medical Systems*, 38:1–16

DOI

10.1007/s10916-014-0043-z

Classification

International peer-reviewed journal; Written for researchers



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Rostering & scheduling

In this paper, we present the Integrated Physician and Surgery Scheduling Problem (IPSSP) as a new approach for solving operating room scheduling problems where staff rosters for the physicians are integrated in the optimization. A mixed integer linear programming formulation is created based on the most frequently observed objective and restrictions of the surgery scheduling and the physician rostering problem in the literature. We analyze schedules by relaxing both surgery and physician related constraints. We then measure the implications of setting these physician preferences on the surgery schedule. Our experiments show two main interesting insights for physician roster schedulers as well as operating theatre scheduling managers.

*Nothing in life is as important as
you think it is when you are
thinking about it.*
Daniel Kahneman



An experimental investigation of metaheuristics for the multi-mode resource-constrained project scheduling problem on new dataset instances

Van Peteghem, Vincent; Vanhoucke, Mario

Tags

artificial data; data generator; meta-heuristic; multi-mode; project management; resource constrained project scheduling

Reference

Van Peteghem, V. and Vanhoucke, M. (2014). An experimental investigation of metaheuristics for the multi-mode resource-constrained project scheduling problem on new dataset instances. *European Journal of Operational Research*, 235:62–72

DOI

10.1016/j.ejor.2013.10.012

Classification

International peer-reviewed journal; Written for researchers; Artificial project data available at www.projectmanagement.ugent.be



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Experimental investigation

In this paper, an overview is presented of the existing metaheuristic solution procedures to solve the multi-mode resource-constrained-project scheduling problem, in which multiple execution modes are available for each of the activities of the project. A fair comparison is made between the different metaheuristic algorithms on the existing benchmark datasets and on a newly generated dataset. Computational results are provided and recommendations for future research are formulated.

You can use all the quantitative data you can get, but you still have to distrust it and use your own intelligence and judgment.
Alvin Toffler



Support Vector Machine regression for project control forecasting

Wauters, Mathieu; Vanhoucke, Mario

Tags

artificial intelligence; earned schedule; earned value management; forecasting; project control; project management; simulation; support vector machines

Reference

Wauters, M. and Vanhoucke, M. (2014). Support vector machine regression for project control forecasting. *Automation in Construction*, 47:92–106

DOI

10.1016/j.autcon.2014.07.014

Classification

International peer-reviewed journal; Written for researchers



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Support vector machines

Support Vector Machines are methods that stem from Artificial Intelligence and attempt to learn the relation between data inputs and one or multiple output values. However, the application of these methods has barely been explored in a project control context. In this paper, a forecasting analysis is presented that compares the proposed Support Vector Regression model with the best performing Earned Value and Earned Schedule methods. The parameters of the SVM are tuned using a cross-validation and grid search procedure, after which a large computational experiment is conducted. The results show that the Support Vector Machine Regression outperforms the currently available forecasting methods. Additionally, a robustness experiment has been set up to investigate the performance of the proposed method when the discrepancy between training and test set becomes larger.

By far, the greatest danger of Artificial Intelligence is that people conclude too early that they understand it.
Eliezer Yudkowsky



Blended learning in Project Management: An overview of the Operations Research & Scheduling group

Vanhoucke, Mario

Tags

blended learning; business game; dynamic scheduling; project management

Reference

Vanhoucke, M. (2014). Blended learning in project management: An overview of the Operations Research & Scheduling group. *Journal of Modern Project Management*, 1 (3):108–121

URL

www.journalmodernpm.com

Classification

International peer-reviewed journal; Written for students; More teaching articles available at www.or-as.be/books

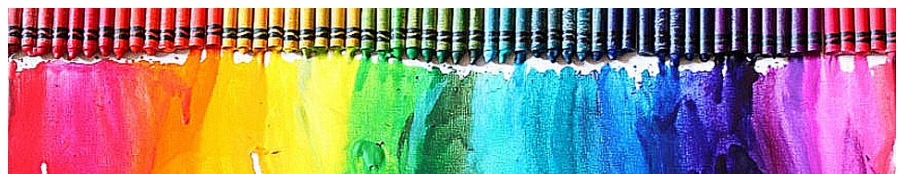


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Blended learning

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 (2013) 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 and Control, but references to other research areas are also given. This overview article can be useful to Project Management (PM) students and teachers, as well as to PM professionals who are interested in the nature of integration between theory and practice that is captured by academic research and that is used in our university teaching activities.

*The whole purpose of education is
to turn mirrors into windows.*
Sydney J. Harris



Teaching Integrated Project Management and Control: Enhancing student learning and engagement

Vanhoucke, Mario

Tags

blended learning; dynamic scheduling; project management

Reference

Vanhoucke, M. (2014). Teaching integrated project management and control: Enhancing student learning and engagement. *Journal of Modern Project Management*, 1 (4):99–107

URL

www.journalmodernpm.com

Classification

International peer-reviewed journal; Written for students; More teaching articles available at www.or-as.be/books



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Student learning

Numerous studies have shown that introducing active learning in the classroom results in a deeper learning experience and a better understanding. In this paper, it will be shown how Ghent University offers students a range of academic possibilities in an active learning environment for a Project Management course designed for and taught to Business Engineering and Civil Engineering students. The aim of this paper is not to discuss the relevance and potential of new learning methods and techniques but rather to illustrate how the existing mix of Project Management tools and techniques used in the classroom can lead to an increased student participation and a deeper reflection about the topics discussed. This paper is potentially interesting to instructors, professionals as well as students interested in the field of Project Management. It is an illustration on how a mix of existing Project Management methodologies used in the classroom helps enhancing student learning and engagement, stimulating interaction between students and professionals as well as creating enthusiasm and passion for the Project Management discipline. A passion that the students might carry with them during their whole professional career.

*It is the supreme art of the teacher
to awaken joy in creative
expression and knowledge.
Albert Einstein*



Praise youth and it will prosper: PMI Belgium's recognition of young PM Potential

Vanhoucke, Mario

Tags

blended learning; project management

Reference

Vanhoucke, M. (2014). Praise youth and it will prosper: Pmi belgium's recognition of young pm potential. *Journal of Modern Project Management*, 2(2):112–117

URL

www.journalmodernpm.com

Classification

International peer-reviewed journal; Written for students and professionals; More teaching articles available at www.or-as.be/books



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PMI Belgium's recognition

The yearly award for the best thesis in Project Management as well as the university contest award for the best group assignment of master's students in the Project Management course module at the Faculty of Economics and Business Administration of Ghent University (Belgium) are two ways to get young master's students involved in the professional PM world. The Belgian chapter of the Project Management Institute (PMI) wants to collaborate with Ghent University to show the relevance of their activities to the most promising group of project managers, our youngsters and future professionals. This collaboration is highly appreciated by both the professionals and the students, and increases the awareness of the importance on the Project Management discipline for their future career.

Praise youth and it will prosper.
Irish Proverb



An integrated nurse staffing and scheduling analysis for longer-term nursing staff allocation problems

Maenhout, Broos; Vanhoucke, Mario

Tags

branch-and-price; column generation; healthcare scheduling; nurse staffing; personnel scheduling; shift scheduling

Reference

Maenhout, B. and Vanhoucke, M. (2013). An integrated nurse staffing and scheduling analysis for longer-term nursing staff allocation problems. *Omega The International Journal of Management Science*, 41:485–499

DOI

10.1016/j.omega.2012.01.002

Classification

International peer-reviewed journal; Written for researchers and professionals



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Nurse staff allocation

The efficient and effective management of nursing personnel is of critical importance in a hospital's environment comprising a vast share of the operational costs. The adopted nurse workforce practices and policies highly affect the nurses' working conditions and the provided quality of care. Policy decisions on the staffing level have an impact on the outcome of the scheduling level and vice versa. Isolated reasoning typically leads to suboptimal decisions often resulting in ineffective outcomes of care. In order to overcome these inefficiencies, we propose in this paper a new integrative nurse staffing and shift scheduling approach. We test and assess the benefits of our approach in a real-life environment. Moreover, we examine the impact of several personnel policies on the staffing decision.

Employees who believe that management is concerned about them as a whole person, not just an employee, are more productive, more satisfied, more fulfilled.
Anne M. Mulcahy



Reconstructing nurse schedules: computational insights in the problem size parameters

Maenhout, Broos; Vanhoucke, Mario

Tags

case study; healthcare scheduling; nurse scheduling; personnel scheduling; rostering; time analysis

Reference

Vanhoucke, M. and Maenhout, B. (2013). Reconstructing nurse schedules: Managerial insights and policy decisions. *Omega The International Journal of Management Science*, 41:903–918

DOI

10.1016/j.omega.2012.10.010

Classification

International peer-reviewed journal; Written for researchers



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Reconstructing nurse schedules

Managing nursing personnel properly is of critical importance as these resources comprise a vast share of the hospital's operational costs. The organisational support and the managerial policy decisions on the scheduling level are important determinants for the nurses' working conditions and the related quality of care. In this paper, we gain insights and understanding in the consequences and outcomes of various personnel re-rostering characteristics and strategies. We explore the boundaries of the time horizon and the nurse staffing size to consider for the nurse re-rostering problem based on computational experiments in a real-life problem environment.

Quality is never an accident. It is
always the result of intelligent
effort.
John Ruskin



Analyzing the nursing organizational structure and process from a scheduling perspective

Maenhout, Broos; Vanhoucke, Mario

Tags

branch-and-price; case study; column generation; healthcare scheduling; nurse staffing; shift scheduling

Reference

Maenhout, B. and Vanhoucke, M. (2013). Analyzing the nursing organizational structure and process from a scheduling perspective. *Health Care Management Science*, 16:177–196

DOI

10.1007/s10729-013-9222-6

Classification

International peer-reviewed journal; Written for researchers and professionals



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Analyzing nurse schedules

The efficient and effective management of nursing personnel is of critical importance in a hospital's environment comprising approximately 25 % of the hospital's operational costs. The nurse organizational structure and the organizational processes highly affect the nurses' working conditions and the provided quality of care. In this paper, we investigate the impact of different nurse organization structures and different organizational processes for a real-life situation in a Belgian university hospital. In order to make accurate nurse staffing decisions, the employed solution methodology incorporates shift scheduling characteristics in order to overcome the deficiencies of the many phase-specific methodologies that are proposed in the academic literature.

I'm a politician. I'm not going to get into a whole range of scientific argument with scientists.

Tony Abbott



An artificial immune system algorithm for the resource availability cost problem

Van Peteghem, Vincent; Vanhoucke, Mario

Tags

artificial immune system; meta-heuristic; project management; project scheduling; resource availability cost problem

Reference

Van Peteghem, V. and Vanhoucke, M. (2013). An artificial immune system algorithm for the resource availability cost problem. *Flexible Services and Manufacturing*, 25:122–144

DOI

10.1007/s10696-011-9117-0

Classification

International peer-reviewed journal; Written for researchers



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Resource availability cost

In this paper, an artificial immune system (AIS) algorithm for the resource availability cost problem (RACP) is presented, in which the total cost of the (unlimited) renewable resources required to complete the project by a prespecified project deadline should be minimized. The AIS algorithm makes use of mechanisms inspired by the vertebrate immune system and includes different algorithmic components, such as a new fitness function, a probability function for the composition of the capacity lists, and a K-means density function in order to avoid premature convergence. All components are explained in detail and computational results for the RACP are presented.

*Research is four things: brains
with which to think, eyes with
which to see, machines with which
to measure and, fourth, money.*
Albert Szent-Gyorgyi



An overview of recent research results and future research avenues using simulation studies in project management

Vanhoucke, Mario

Tags

dynamic scheduling; earned schedule; earned value management; project management; schedule risk analysis; simulation

Reference

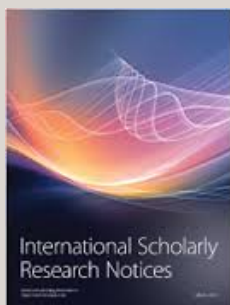
Vanhoucke, M. (2013). An overview of recent research results and future research avenues using simulation studies in project management. *ISRN Computational Mathematics*, Article ID 513549:1–19

DOI

10.1155/2013/513549

Classification

International peer-reviewed journal; Written for researchers



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Simulation overview

This paper gives an overview of three simulation studies in dynamic project scheduling integrating baseline scheduling with risk analysis and project control. This integration is known in the literature as dynamic scheduling. An integrated project control method is presented using a project control simulation approach that combines the three topics into a single decision support system. The method makes use of Monte Carlo simulations and connects schedule risk analysis (SRA) with earned value management (EVM). A corrective action mechanism is added to the simulation model to measure the efficiency of two alternative project control methods. At the end of the paper, a summary of recent and state-of-the-art results is given, and directions for future research based on a new research study are presented.

If you steal from one author it's plagiarism. If you steal from many it's research.
Wilson Mizner



Project baseline scheduling: An overview of past experiences

Vanhoucke, Mario

Tags

case study; dynamic scheduling;
project management; project
scheduling

Reference

Vanhoucke, M. (2013). Project
baseline scheduling: An
overview of past experiences.
*Journal of Modern Project Man-
agement*, 1(2):18–27

URL

www.journalmodernpm.com

Classification

International peer-reviewed jour-
nal; Written for students and pro-
fessionals



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Scheduling experience

Dynamic project scheduling is a term used to refer to the dynamic nature of project management. It consists of three dimensions, known as baseline scheduling, schedule risk analysis and project control (Uyttewaal, 2005; Vanhoucke, 2012). In previous studies, it has been shown that both the schedule risk analysis and project control should go hand in hand as 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. In an article in the International Journal of Project Management (Vanhoucke, 2012), the project control dimension was highlighted based on a comparison between academic results obtained on fictitious project data and additional tests performed on a set of real-life data from 8 Belgian companies from various sectors. However, little or nothing has been said about the first dimension of dynamic scheduling: the construction of a project baseline schedule. In the current article, a similar approach to the previously published article will be followed. Based on the extensive knowledge of the algorithmic developments in the academic literature and on the past experience of using some of these (adapted) algorithms in a practical environment, it will be illustrated how and why research can contribute positively to practice when constructing a project baseline schedule. In doing so, we believe that the gap between academic results and practical relevance is bridged, gradually moving the dynamic project scheduling discipline to a higher level.

*If we could sell our experiences for
what they cost us, we'd all be
millionaires.
Pauline Phillips*



An artificial immune system based approach for solving the nurse re-rostering system

Maenhout, Broos; Vanhoucke, Mario

Tags

artificial immune system;
healthcare scheduling; meta-
heuristic; personnel scheduling;
rerostering

Reference

Vanhoucke, M. and Maenhout, B.
(2013). An artificial immune sys-
tem based approach for solving
the nurse re-rostering problem.
*Lecture Notes in Computer Sci-
ence*, 7832:97–108

DOI

10.1007/978-3-642-37198-1_9

Classification

International peer-reviewed jour-
nal; Written for researchers



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Artificial nurse rostering

Personnel resources can introduce uncertainty in the operational processes. Constructed personnel rosters can be disrupted and render infeasible rosters. Feasibility has to be restored by adapting the original announced personnel rosters. In this paper, an Artificial Immune System for the nurse re-rostering problem is presented. The proposed algorithm uses problem-specific and even roster-specific mechanisms which are inspired on the vertebrate immune system. We observe the performance of the different algorithmic components and compare the proposed procedure with the existing literature.

*Few great men would have got
past personnel.
Paul Goodman*



Integrated project controls: using operations research methods to improve the efficiency of project control

Vanhoucke, Mario

Tags

dynamic scheduling; project management; schedule risk analysis

Reference

Vanhoucke, M. (2013). Integrated project controls: Using operations research methods to improve the efficiency of project control. In J.S. Yeomans, R. M. and Nordlander, T., editors, *Lecture Notes in Management Science*, pages 174–175, Lisbon, Portugal

URL

www.orlabanalytics.ca

Classification

International peer-reviewed journal; Written for researchers



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Efficiency improvement

Baseline scheduling and risk analysis go hand in hand and are crucial preparatory dimensions to provide information for the project control phase. One of the central lessons in training sessions to project managers is that scheduling without any form of risk management makes no sense since it then boils down to an academic and deterministic optimization exercise without much real life value. A project schedule is a dynamic instrument that needs to be adapted when necessary. Project managers have to deal with a continuous stream of unexpected events and need to take corrective actions to bring projects back on track or to update the initial estimates and expectations to a more realistic scenario. In that respect, a dynamic project schedule is the ideal tool to provide information and to support the corrective actions, and hence, the project baseline schedule acts as a point-of-reference to support these actions, rather than a forecast of the future that needs to be followed at all times.

*The market controls everything,
but the market has no heart.*
Anita Roddick



A hybrid genetic algorithm for the single machine maximum lateness problem with release times and family setups

Sels, Veronique; Vanhoucke, Mario

Tags

genetic algorithm; meta-heuristic; production scheduling; single machine scheduling

Reference

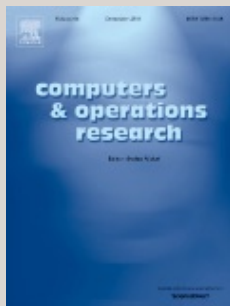
Sels, V. and Vanhoucke, M. (2012). A hybrid genetic algorithm for the single machine maximum lateness problem with release times and family setups. *Computers & Operations Research*, 39:2346–2358

DOI

10.1016/j.cor.2011.12.014

Classification

International peer-reviewed journal; Written for researchers



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Family setup times

We consider the problem of scheduling a number of jobs, each job having a release time, a processing time, a due date and a family setup time, on a single machine with the objective of minimizing the maximum lateness. We develop a hybrid genetic algorithm and validate its performance on a newly developed diverse data set. We perform an extensive study of local search algorithms, based on the trade-off between intensification and diversification strategies, taking the characteristics of the problem into account. We combine different local search neighborhood structures in an intelligent manner to further improve the solution quality. We use the hybrid genetic algorithm to perform a comprehensive analysis of the influence of the different problem parameters on the average maximum lateness value and the performance of the algorithm(s).

*Genetics is about how information
is stored and transmitted between
generations.*

John Maynard Smith



A comparison of priority rules for the job shop scheduling problem under different flow time- and tardiness-related objective functions

Sels, Veronique; Gheysen, Nele; Vanhoucke, Mario

Tags

job shop scheduling; priority rules; production scheduling; sequence-dependent setup times

Reference

Sels, V., Gheysen, N., and Vanhoucke, M. (2012). A comparison of priority rules for the job shop scheduling problem under different flow time- and tardiness-related objective functions. *International Journal of Production Research*, 50:1–16

DOI

10.1080/00207543.2011.611539

Classification

International peer-reviewed journal; Written for researchers



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Priority rules

In this paper, a comparison and validation of various priority rules for the job shop scheduling problem under different objective functions is made. In a first computational experiment, 30 priority rules from the literature are used to schedule job shop problems under two flow time-related and three tardiness-related objectives. Based on this comparative study, the priority rules are extended to 13 combined scheduling rules in order to improve the performance of the currently best-known rules from the literature. Moreover, the best-performing priority rules on each of these five objective functions are combined into hybrid priority rules in order to be able to optimise various objectives at the same time. In a second part of the computational experiment, the robustness on the relative ranking of the performance quality is checked for the various priority rules when applied on larger problem instances, on the extension of multiple machines possibilities per job as well as on the introduction of sequence-dependent setup times. Moreover, the influence of dynamic arrivals of jobs has also been investigated to check the robustness on the relative ranking of the performance quality between static and dynamic job arrivals. The results of the computational experiments are presented and critical remarks and future research avenues are suggested.

Jealousy is the fear of comparison.
Max Frisch



Measuring the efficiency of project control using fictitious and empirical project data

Vanhoucke, Mario

Tags

case study; dynamic scheduling; earned schedule; earned value management; project control; project management; schedule risk analysis; simulation

Reference

Vanhoucke, M. (2012). Measuring the efficiency of project control using fictitious and empirical project data. *International Journal of Project Management*, 30:252–263

DOI

10.1016/j.ijproman.2011.05.006

Classification

International peer-reviewed journal; Written for researchers and professionals



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Control efficiency

Dynamic scheduling refers to the integration of three important phases in the life cycle of a project: baseline scheduling, schedule risk analysis and project control. In this paper, the efficiency of controlling a project is measured and evaluated using a Monte-Carlo simulation study on fictitious and empirical project data. In the study, the construction of a project baseline schedule acts as a point-of-reference for the schedule risk analysis and project control phases. The sensitivity information obtained by the schedule risk analyses (SRA) and the earned value management (EVM) information obtained during project control serve as early warning control parameters that trigger corrective actions to bring projects back on track in case of problems. The focus in this paper lies on the time performance of a project, and not on the prediction and controlling of the project costs. The contribution of this paper is twofold. First, this paper summarizes the main conclusions of various experiments performed in a large simulation study on the efficiency of project control techniques and the ability to trigger corrective actions in case of project problems. The main purpose of these simulation experiments is to understand why EVM and/or SRA work so well in some projects and fail so miserably in others. This study has been awarded by the International Project Management Association in 2008 on the IPMA world congress in Rome (Italy). Secondly, the paper compares the results obtained on fictitious project data with additional tests performed on a set of real-life data from 8 Belgian companies from various sectors.

Management is efficiency in climbing the ladder of success; leadership determines whether the ladder is leaning against the right wall.
Stephen Covey



Operations research and dynamic project scheduling: When research meets practice

Vanhoucke, Mario

Tags

dynamic scheduling; project management; schedule risk analysis

Reference

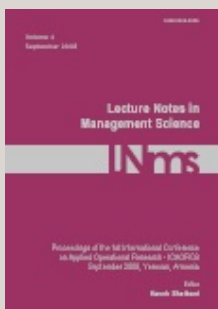
Vanhoucke, M. (2012). Operations research and dynamic project scheduling: When research meets practice. In Luangpaiboon, P., Moz, M., and Dedoussis, V., editors, *Lecture Notes in Management Science*, pages 1–8, Bangkok, Thailand

URL

www.orlabanalytics.ca

Classification

International peer-reviewed journal; Written for researchers and professionals



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Operations Research

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.

Writing means sharing. It's part of the human condition to want to share things - thoughts, ideas, opinions.
Paulo Coelho



Multi-mode resource-constrained project scheduling using RCPSP and SAT solvers

Coelho, José; Vanhoucke, Mario

Tags

boolean satisfiability problem; genetic algorithm; meta-heuristic; multi-mode; project management; resource constrained project scheduling

Reference

Coelho, J. and Vanhoucke, M. (2011). Multi-mode resource-constrained project scheduling using RCPSP and SAT solvers. *European Journal of Operational Research*, 213:73–82

DOI

10.1016/j.ejor.2011.03.019

Classification

International peer-reviewed journal; Written for researchers; Artificial project data available at www.projectmanagement.ugent.be



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RCPSP & SAT

This paper reports on a new solution approach for the well-known multi-mode resource-constrained project scheduling problem (MRCPSP). This problem type aims at the selection of a single activity mode from a set of available modes in order to construct a precedence and a (renewable and non-renewable) resource feasible project schedule with a minimal makespan. The problem type is known to be NP-hard and has been solved using various exact as well as (meta-)heuristic procedures. The new algorithm splits the problem type into a mode assignment and a single mode project scheduling step. The mode assignment step is solved by a satisfiability (SAT) problem solver and returns a feasible mode selection to the project scheduling step. The project scheduling step is solved using an efficient meta-heuristic procedure from literature to solve the resource-constrained project scheduling problem (RCPSP). However, unlike many traditional meta-heuristic methods in literature to solve the MRCPSP, the new approach executes these two steps in one run, relying on a single priority list. Straightforward adaptations to the pure SAT solver by using pseudo boolean non-renewable resource constraints has led to a high quality solution approach in a reasonable computational time. Computational results show that the procedure can report similar or sometimes even better solutions than found by other procedures in literature, although it often requires a higher CPU time.

The key is not to prioritize what's on your schedule, but to schedule your priorities.
Stephen Covey



An evolutionary approach for the nurse rerostering problem

Maenhout, Broos; Vanhoucke, Mario

Tags

evolutionary algorithm;
healthcare scheduling; nurse
scheduling; rerostering

Reference

Maenhout, B. and Vanhoucke, M. (2011). An evolutionary approach for the nurse rerostering problem. *Computers & Operations Research*, 38:1400–1411

DOI

10.1016/j.cor.2010.12.012

Classification

International peer-reviewed journal;
Written for researchers



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Evolutionary rerostering

The personnel scheduler constructs a deterministic personnel roster that determines the line-of-work for each personnel member. When unexpected events disrupt this roster, the feasibility needs to be restored by constructing a new workable roster. The scheduler must reassign the set of employees in order to cover the disrupted shift such that the staffing requirements and the time-related personnel constraints remain satisfied. In this paper, we propose an evolutionary meta-heuristic to solve the nurse rerostering problem. We show that the proposed procedure performs consistently well under many different circumstances. We test different optimisation strategies and compare our procedure with the existing literature on a dataset that is carefully designed in a controlled and varied way.

*I take no pleasure in the fact that
the scientific predictions I've
relayed to popular audiences turn
out to be true.*
Al Gore



A hybrid single and dual population search procedure for the job shop scheduling problem

Sels, Veronique; Craeymeersch, Kjeld; Vanhoucke, Mario

Tags

genetic algorithm; job shop scheduling; meta-heuristic; production scheduling; scatter search

Reference

Sels, V., Craeymeersch, K., and Vanhoucke, M. (2011). A hybrid single and dual population search procedure for the job shop scheduling problems. *European Journal of Operational Research*, 215:512–523

DOI

10.1016/j.ejor.2011.06.031

Classification

International peer-reviewed journal; Written for researchers; Data and solutions available at www.projectmanagement.ugent.be



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Job shop scheduling

This paper presents a genetic algorithm and a scatter search procedure to solve the well-known job shop scheduling problem. In contrast to the single population search performed by the genetic algorithm, the scatter search algorithm splits the population of solutions in a diverse and high-quality set to exchange information between individuals in a controlled way. The extension from a single to a dual population, by taking problem specific characteristics into account, can be seen as a stimulator to add diversity in the search process. This has a positive influence on the important balance between intensification and diversification. Computational experiments verify the benefit of this diversity on the effectiveness of the meta-heuristic search process. Various algorithmic parameters from literature are embedded in both procedures and a detailed comparison is made. A set of standard instances is used to compare the different approaches and the best obtained results are benchmarked against heuristic solutions found in literature.

Plans are nothing; planning is everything.
Dwight D. Eisenhower



Applying a hybrid job shop procedure to a Belgian manufacturing company producing industrial wheels and castors in rubber

Sels, Veronique; Steen, Frederic; Vanhoucke, Mario

Tags

case study; job shop scheduling; meta-heuristic; production scheduling; shifting bottleneck; tabu search

Reference

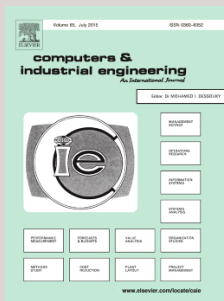
Sels, V., Steen, F., and Vanhoucke, M. (2011). Applying a hybrid job shop procedure to a Belgian manufacturing company producing industrial wheels and castors in rubber. *Computers & Industrial Engineering*, 61:697–708

DOI

10.1016/j.cie.2011.04.023

Classification

International peer-reviewed journal; Written for researchers and professionals



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Industrial wheels

In this paper, several methods for job shop scheduling are combined, adjusted and successfully applied to a real-world scheduling problem at a Belgian manufacturer producing industrial wheels and castors in rubber. The procedure is an extension of a hybrid shifting bottleneck procedure with a tabu search algorithm while incorporating various company specific constraints. The various extensions to cope with the company specific constraints have a strong similarity with the complex job shop problem formulation of Mason, Fowler, and Carlyle (2002). The new procedure is used as a simulation engine to test the relevance of various scenarios in order to improve the current planning approach of the company. A detailed computational experiment highlights the main contribution of the novel procedure for the company.

*For me, true luxury can be caviar
or a day with no meetings, no
appointments and no schedule.*

Michael Kors



On the dynamic use of project performance and schedule risk information during project tracking

Vanhoucke, Mario

Tags

dynamic scheduling; earned schedule; earned value management; project control; project management; schedule risk analysis; simulation

Reference

Vanhoucke, M. (2011). On the dynamic use of project performance and schedule risk information during project tracking. *Omega The International Journal of Management Science*, 39:416–426

DOI

10.1016/j.omega.2010.09.006

Classification

International peer-reviewed journal; Written for researchers and professionals



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A goal without a plan is just a wish.
Antoine de Saint-Exupéry

Risk & control

Project scheduling, risk analysis and project tracking are key parameters to a project's success or failure. Research on the relative sensitivity of project activities during the project scheduling phase as well as research on project performance measurement during project progress have been published throughout the academic literature and the popular press. Obviously, the interest in activity sensitivity information and project performance measurement from both the academics and the practitioners lies in the need to focus a project manager's attention on those activities that influence the performance of the project. When management has knowledge about the current project performance and has a certain feeling of the relative sensitivity of the various project activities on the project objective, a better management focus and a more accurate response during project tracking should positively contribute to the overall performance of the project. In this article, two alternative project tracking methods to detect project problems are presented and their efficiency on the quality of corrective actions to bring the project back on track is measured and evaluated. A bottom-up and a top-down project tracking approach within a corrective action framework is applied on a large and diverse set of fictitious projects that are subject to Monte-Carlo simulations to simulate fictitious project progress under uncertainty. The top-down tracking approach relies on earned value management performance metrics, while the bottom-up tracking mechanism makes use of the well-known schedule risk analysis method. A computational experiment shows that a top-down project tracking approach is highly efficient for project networks with a serial activity structure while a bottom-up approach performs better in a parallel structured project network. Moreover, it will also be shown that dynamic thresholds to trigger corrective actions, which gradually increase or decrease the project manager's attention along the project progress, outperform the static thresholds for both tracking approaches.

Using resource scarceness characteristics to solve the multi-mode resource-constrained project scheduling problem

Van Peteghem, Vincent; Vanhoucke, Mario

Tags

meta-heuristic; multi-mode; project management; resource analysis; resource constrained project scheduling; scatter search

Reference

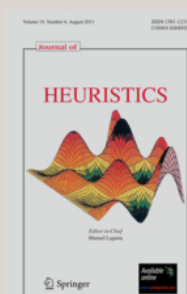
Van Peteghem, V. and Vanhoucke, M. (2011). Using resource scarceness characteristics to solve the multi-mode resource-constrained project scheduling problem. *Journal of Heuristics*, 13:77–93

DOI

10.1007/s10732-010-9152-0

Classification

International peer-reviewed journal; Written for researchers



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Resource scarceness

In the past decades, resource parameters have been introduced in project scheduling literature to measure the scarceness of resources of a project instance. In this paper, we incorporate these resource scarceness parameters in the search process to solve the multi-mode resource constrained project scheduling problem, in which multiple execution modes are available for each activity in the project. Therefore, we propose a scatter search algorithm, which is executed with different improvement methods, each tailored to the specific characteristics of different renewable and nonrenewable resource scarceness values. Computational results prove the effectiveness of the improvement methods and reveal that the procedure is among the best performing competitive algorithms in the open literature.

Live life to the fullest, for the future is scarce.
Nick Carter



A hybrid dual-population genetic algorithm for the single machine maximum lateness problem

Sels, Veronique; Vanhoucke, Mario

Tags

genetic algorithm; meta-heuristic; production scheduling; single machine scheduling

Reference

Sels, V. and Vanhoucke, M. (2011). A hybrid dual-population genetic algorithm for the single machine maximum lateness problem. *Lecture Notes in Computer Science*, 6622:14–25

DOI

10.1007/978-3-642-20364-0_2

Classification

International peer-reviewed journal; Written for researchers



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Single machine scheduling

We consider the problem of scheduling a number of jobs, each job having a release time, a processing time and a due date, on a single machine with the objective of minimizing the maximum lateness. We developed a hybrid dual-population genetic algorithm and compared its performance with alternative methods on a new diverse data set. Extensions from a single to a dual population by taking problem specific characteristics into account can be seen as a stimulator to add diversity in the search process, which has a positive influence on the important balance between intensification and diversification. Based on a comprehensive literature study on genetic algorithms in single machine scheduling, a fair comparison of genetic operators was made.

Most intellectuals today have a phobia of any explanation of the mind that invokes genetics.
Steven Pinker



Branching strategies in a branch-and-price approach for a multiple objective nurse scheduling problem

Maenhout, Broos; Vanhoucke, Mario

Tags

branch-and-price; column generation; healthcare scheduling; nurse scheduling; personnel scheduling

Reference

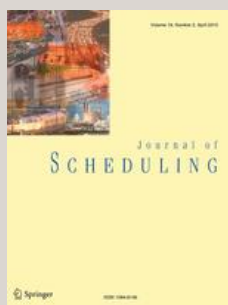
Maenhout, B. and Vanhoucke, M. (2010). Branching strategies in a branch-and-price approach for a multiple objective nurse scheduling problem. *Journal of Scheduling*, 13:77–93

DOI

10.1007/s10951-009-0108-x

Classification

International peer-reviewed journal; Written for researchers



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Branching strategies

The efficient management of nursing personnel is of critical importance in a hospital's environment comprising a vast share of the hospital's operational costs. The nurse scheduling process affects highly the nurses' working conditions, which are strongly related to the provided quality of care. In this paper, we consider the rostering over a midterm period that involves the construction of duty timetables for a set of heterogeneous nurses. In scheduling nursing personnel, the head nurse is typically confronted with various (conflicting) goals complying with different priority levels which represent the hospital's policies and the nurses' preferences. In constructing a nurse roster, nurses need to be assigned to shifts in order to maximize the quality of the constructed timetable satisfying the case-specific time related constraints imposed on the individual nurse schedules. Personnel rostering in healthcare institutions is a highly constrained and difficult problem to solve and is known to be NP-hard. In this paper, we present an exact branch-and-price algorithm for solving the nurse scheduling problem incorporating multiple objectives and discuss different branching and pruning strategies. Detailed computational results are presented comparing the proposed branching strategies and indicating the beneficial effect of various principles encouraging computational efficiency.

In wilderness I sense the miracle of life, and behind it our scientific accomplishments fade to trivia.
Charles Lindbergh



A hybrid scatter search heuristic for personalized crew rostering in the airline industry.

Maenhout, Broos; Vanhoucke, Mario

Tags

branch-and-price; crew scheduling; meta-heuristic; personnel scheduling; scatter search

Reference

Maenhout, B. and Vanhoucke, M. (2010). A hybrid scatter search heuristic for personalized crew rostering in the airline industry. *European Journal of Operational Research*, 206:155–167

DOI

10.1016/j.ejor.2010.01.040

Classification

International peer-reviewed journal; Written for researchers



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Nurse rerostering

The crew scheduling problem in the airline industry is extensively investigated in the operations research literature since efficient crew employment can drastically reduce operational costs of airline companies. Given the flight schedule of an airline company, crew scheduling is the process of assigning all necessary crew members in such a way that the airline is able to operate all its flights and constructing a roster line for each employee minimizing the corresponding overall cost for personnel. In this paper, we present a scatter search algorithm for the airline crew rostering problem. The objective is to assign a personalized roster to each crew member minimizing the overall operational costs while ensuring the social quality of the schedule. We combine different complementary meta-heuristic crew scheduling combination and improvement principles. Detailed computational experiments in a real-life problem environment are presented investigating all characteristics of the procedure. Moreover, we compare the proposed scatter search algorithm with optimal solutions obtained by an exact branch-and-price procedure and a steepest descent variable neighbourhood search.

*When it comes to personnel issues,
I act professionally and respectful
of former employees. I just assume
that's a two-way street. It's
disappointing when it's not.*
Michele Bachmann



Using activity sensitivity and network topology information to monitor project time performance.

Vanhoucke, Mario

Tags

project control; project management; schedule risk analysis; simulation

Reference

Vanhoucke, M. (2010). Using activity sensitivity and network topology information to monitor project time performance. *Omega The International Journal of Management Science*, 38:359–370

DOI

10.1016/j.omega.2009.10.001

Classification

International peer-reviewed journal; Written for researchers and professionals



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Network topology

The interest in activity sensitivity from both the academics and the practitioners lies in the need to focus a project manager's attention on those activities that influence the performance of the project. When management has a certain feeling of the relative sensitivity of the various parts (activities) on the project objective, a better management's focus and a more accurate response during project tracking should positively contribute to the overall performance of the project. In the current research manuscript, a simulation study is performed to measure the ability of four basic sensitivity metrics to dynamically improve the time performance during project execution. We measure the use of sensitivity information to guide the corrective action decision making process to improve a project's time performance, while varying the degree of management's attention. A large amount of simulation runs are performed on a large set of fictitious project networks generated under a controlled design.

*Risk comes from not knowing
what you're doing.*
Warren Buffett



A scatter search heuristic for maximising the net present value of a resource-constrained project with fixed activity cash flows

Vanhoucke, Mario

Tags

cash flows; meta-heuristic; net present value; project management; resource constrained project scheduling; scatter search

Reference

Vanhoucke, M. (2010). A scatter search heuristic for maximising the net present value of a resource-constrained project with fixed activity cash flow. *International Journal of Production Research*, 48:1983–2001

DOI

10.1080/00207540802010781

Classification

International peer-reviewed journal; Written for researchers; Data and solutions available at www.projectmanagement.ugent.be



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Fixed activity cash flows

In this paper, we present a meta-heuristic algorithm for the resource-constrained project scheduling problem with discounted cash flows. We assume fixed payments associated with the execution of project activities and develop a heuristic optimisation procedure to maximise the net present value of a project subject to the precedence and renewable resource constraints. We investigate the use of a bi-directional generation scheme and a recursive forward/backward improvement method from literature and embed them in a meta-heuristic scatter search framework. We generate a large dataset of project instances under a controlled design and report detailed computational results. The solutions and project instances can be downloaded from a website in order to facilitate comparison with future research attempts.

I'm a cash flow guy. If it doesn't make me money today, forget about it.

Robert Kiyosaki



A genetic algorithm for the preemptive and non-preemptive multi-mode resource-constrained project scheduling problem

Van Peteghem, Vincent; Vanhoucke, Mario

Tags

genetic algorithm; meta-heuristic; multi-mode; preemption; project management; resource constrained project scheduling

Reference

Van Peteghem, V. and Vanhoucke, M. (2010). A genetic algorithm for the preemptive and non-preemptive multi-mode resource-constrained project scheduling problem. *European Journal of Operational Research*, 201:409–418

DOI

10.1016/j.ejor.2009.03.034

Classification

International peer-reviewed journal; Written for researchers



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Activity preemption

In this paper we present a genetic algorithm for the multi-mode resource-constrained project scheduling problem (MRCPSP), in which multiple execution modes are available for each of the activities of the project. We also introduce the preemptive extension of the problem which allows activity splitting (P-MRCPSP). To solve the problem, we apply a bi-population genetic algorithm, which makes use of two separate populations and extend the serial schedule generation scheme by introducing a mode improvement procedure. We evaluate the impact of preemption on the quality of the schedule and present detailed comparative computational results for the MRCPSP, which reveal that our procedure is amongst the most competitive algorithms.

I'm one of those people you hate because of genetics. It's the truth.
Brad Pitt



Introducing optimization techniques to students: An exam case distribution model

Vanhoucke, Mario

Tags

blended learning; linear programming

Reference

Vanhoucke, M. (2010). Introducing optimization techniques to students: An exam case distribution model. *INFORMS Transactions on Education*, 10:53–61

DOI

10.1287/ited.1090.0040

Classification

International peer-reviewed journal; Written for students



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Exam case distribution

In this paper, an integer programming (IP) model is presented to assign MBA and undergraduate students to groups to solve an exam case in an operations research (O.R.) course. It is assumed that the students have a basic understanding of mathematical programming and are now ready to build their first real-life model in class. Thanks to the direct link with the student's situation and the immediate repercussion on the exam assignment, students can quickly understand the problem and are willing to help to define the problem in class. The example illustrates many O.R.-related issues, such as the balance between problem complexity and solution quality, and the need for dynamic rather than static models. Thanks to its simplicity and practicality, this exercise is an ideal tool to make the often complex domain of O.R. more accessible.

*I'm no model lady. A model's just
an imitation of the real thing.*
Mae West



The impact of incorporating nurse-specific characteristics in a cyclical scheduling approach

Maenhout, Broos; Vanhoucke, Mario

Tags

case study; healthcare scheduling; personnel scheduling; timetabling

Reference

Maenhout, B. and Vanhoucke, M. (2009). The impact of incorporating nurse-specific characteristics in a cyclical scheduling approach. *Journal of the Operational Research Society*, 60:1683–1698

DOI

10.1057/jors.2008.131

Classification

International peer-reviewed journal; Written for researchers and professionals



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Cyclical scheduling

Nursing staff in various hospitals in Belgium are principally cyclically scheduled. The employed cyclic schedules embody, however, only a weak reflection of the ultimate nurse rosters constructed for a specific month. In this paper, we investigate the benefits of integrating nurse-specific characteristics in the cyclic scheduling approach. Moreover, we analyse to what extent these characteristics should be incorporated and compare this approach with a general and more robust cyclical scheduling approach and the flexible acyclical rostering of nursing personnel.

Good management is the art of making problems so interesting and their solutions so constructive that everyone wants to get to work and deal with them.
Paul Hawken



On the characterization and generation of nurse scheduling problem instances

Vanhoucke, Mario; Maenhout, Broos

Tags

artificial data; data generator; healthcare scheduling; nurse scheduling; personnel scheduling

Reference

Vanhoucke, M. and Maenhout, B. (2009). On the characterization and generation of nurse scheduling problem instances. *European Journal of Operational Research*, 196:457–467

DOI

10.1016/j.ejor.2008.03.044

Classification

International peer-reviewed journal; Written for researchers; Data generator available at www.projectmanagement.ugent.be



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Artificial nurse data

Due to its complexity and relevance in practice, many different procedures have been proposed in the operations research literature to solve the well-known nurse scheduling problem (NSP). The NSP assigns nurses to shifts per day maximizing the overall quality of the roster while taking various constraints into account. The often highly case-specific workplace conditions in hospital departments have resulted in the development of dedicated (meta-)heuristics to find a workable schedule in an acceptable time limit. However, in spite of research community posing a growing need for benchmarking, these procedures lack any base for comparison. In this paper, we propose a range of complexity indicators which characterize nurse scheduling problem instances, and a problem generator in order to construct a comparative test framework for various solution procedures for the NSP. We show that the different complexity indicators for the NSP presented in this paper predict the computational effort of a particular NSP instance for a particular solution procedure. Moreover, the comparison of procedures and good predictions of their performance allow the a priori selection of the best solution procedure, based on the simple calculation of the indicators. Hence, with the developed NSP generator those indicators can facilitate the evaluation of existing and future research techniques. Tests on a simple IP model illustrate the use of the proposed indicators.

*In the spirit of science, there really
is no such thing as a failed
experiment. Any test that yields
valid data is a valid test.*
Adam Savage



A finite-capacity production scheduling procedure for a Belgian steel company

Vanhoucke, Mario; Debels, Dieter

Tags

case study; machine scheduling;
production scheduling

Reference

Vanhoucke, M. and Debels, D. (2009). A finite-capacity production scheduling procedure for a Belgian steel company. *International Journal of Production Research*, 47:561–584

DOI

10.1080/00207540701441970

Classification

International peer-reviewed journal;
Written for researchers and professionals



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Arcelor Mittal

We present a multi-objective finite-capacity production scheduling algorithm for an integrated steel company located in Belgium. The two-stage optimization model takes various company-specific constraints into account and optimizes various, often conflicting, weighted objectives. A first machine assignment stage determines the routing of an individual order through the network while a second scheduling stage makes a detailed timetable for each operation for all orders. The procedure has been tested on randomly generated data instances sampled from real-life data from the steel company. We report promising computational results and illustrate the flexibility of the optimization model with respect to the various weights in the multi-objective function.

*If we knew what it was we were
doing, it would not be called
research, would it?*
Albert Einstein



An artificial immune system for the multi-mode resource-constrained project scheduling problem

Van Peteghem, Vincent; Vanhoucke, Mario

Tags

artificial immune system;
meta-heuristic; multi-mode;
project management; resource
constrained project scheduling

Reference

Van Peteghem, V. and Vanhoucke, M. (2009). A artificial immune system for the multi-mode resource-constrained project scheduling problem. *Lecture Notes in Computer Science*, 5482:85–96

DOI

10.1007/978-3-642-01009-5_8

Classification

International peer-reviewed journal; Written for researchers



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Artificial immune system

In this paper, an Artificial Immune System (AIS) for the multi-mode resource-constrained project scheduling problem (MRCPSP), in which multiple execution modes are available for each of the activities of the project, is presented. The AIS algorithm makes use of mechanisms which are inspired on the vertebrate immune system performed on an initial population set. This population set is generated with a controlled search method, based on experimental results which revealed a link between predefined profit values of a mode assignment and its makespan. The impact of the algorithmic parameters and the initial population generation method is observed and detailed comparative computational results for the MRCPSP are presented.

*Look deep into nature, and then
you will understand everything
better.*
Albert Einstein



A genetic algorithm for net present value maximization for resource constrained projects

Vanhoucke, Mario

Tags

cash flows; genetic algorithm; meta-heuristic; net present value; project management; resource constrained project scheduling

Reference

Vanhoucke, M. (2009). A genetic algorithm for net present value maximization for resource constrained projects. *Lecture Notes in Computer Science*, 5482:13–24

DOI

10.1007/978-3-642-01009-5_2

Classification

International peer-reviewed journal; Written for researchers



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Genetic cash flow algorithm

In this paper, we present a new genetic algorithm for the resource-constrained project scheduling problem with discounted cash flows and investigate the trade-off between a project's net present value and its corresponding makespan. We consider a problem formulation where the pre-specified project deadline is not set as a hard constraint, but rather as a soft constraint that can be violated against a certain penalty cost. the genetic algorithm creates children from parents taken from three different populations, each containing relevant information about the (positive or negative) activity cash flows. We have tested various parent selection methods based on four crossover operators taken from literature and present extensive computational results.

The neuroscience area - which is absolutely in its infancy - is much more important than genetics.

Leon Kass



Diversity in resource consumption patterns and robustness of costing systems to errors

Labro, Eva; Vanhoucke, Mario

Tags

activity based costing; management accounting; simulation

Reference

Labro, E. and Vanhoucke, M. (2008). Diversity in resource consumption patterns and robustness of costing system to errors. *Management Science*, 54:1715–1730

DOI

10.1287/mnsc.1080.0885

Classification

International peer-reviewed journal; Written for researchers and professionals



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Diversity in costing systems

Practitioners and academics hypothesize that when there is high diversity in resource consumption patterns, costing systems are more sensitive to errors. Given that firms' resources to enhance costing accuracy are typically constrained, it is argued that costing system refinement efforts should be focused on such cases, where they are likely to be most effective. However, little guidance is available on how to identify those situations where costing system refinement efforts (such as introducing an activity-based costing system) are likely to pay off most in terms of increased accuracy. Further, to our knowledge, the existing guidance provided by this high diversity rule of thumb has never been empirically tested. Using a simulation method, we address these issues in this paper. Specifically, we model various aspects, and degrees, of diversity in the resource consumption patterns to be reflected by the costing system and find that more diversity in resource consumption patterns only leads to increased costing system sensitivity to errors for some of the aspects of diversity studied. We also identify situations in which allocating costing system refinement resources to cases characterized by high diversity in resource consumption patterns is detrimental to improved accuracy.

There's no business like show business, but there are several businesses like accounting.
David Letterman



Comparison and hybridization of crossover operators for the nurse scheduling problem

Maenhout, Broos; Vanhoucke, Mario

Tags

genetic algorithm; healthcare scheduling; meta-heuristic; nurse scheduling

Reference

Maenhout, B. and Vanhoucke, M. (2008). Comparison and hybridization of crossover operators for the nurse scheduling problem. *Annals of Operations Research*, 159:333–353

DOI

10.1007/s10479-007-0268-z

Classification

International peer-reviewed journal; Written for researchers



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Comparing crossovers

In this paper, we present a hybrid genetic algorithm for the well-known nurse scheduling problem (NSP). The NSP involves the construction of roster schedules for nursing staff in order to maximize the quality of the roster schedule subject to various hard constraints. In the literature, several genetic algorithms have been proposed to solve the NSP under various assumptions. The contribution of this paper is twofold. First, we extensively compare the various crossover operators and test them on a standard dataset in a solitary approach. Second, we propose several options to hybridize the various crossover operators.

The three most dreaded words in the English language are 'negative cash flow'.
David Tang



An evaluation of the adequacy of project network generators with systematically sampled networks

Vanhoucke, Mario; Coelho, José; Debels, Dieter; Maenhout, Broos; Tavares, Luis Valadares

Tags

artificial data; data generator;
network analysis; project
management

Reference

Vanhoucke, M., Coelho, J.,
Debels, D., Maenhout, B., and
Tavares, L. (2008). An evalua-
tion of the adequacy of project
network generators with sys-
tematically sampled networks.
*European Journal of Operational
Research*, 187:511–524

DOI

10.1016/j.ejor.2007.03.032

Classification

International peer-reviewed jour-
nal; Written for researchers;
Project network generator avail-
able at www.projectmanagement.ugent.be



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Generating networks II

This paper evaluates and compares different network generators to generate project scheduling problem instances based on indicators measuring the topological network structure. We review six topological network indicators in order to describe the detailed structure of a project network. These indicators were originally developed by [L.V. Tavares, J.A. Ferreira and J.S. Coelho, The risk of delay of a project in terms of the morphology of its network, *European Journal of Operational Research* 119 (1999), 510-537] and have been modified, or sometimes completely replaced, by alternative indicators to describe the network topology. The contribution of this paper is twofold. Firstly, we generate a large amount of different networks with four project network generators. Our general conclusions are that none of the network generators are able to capture the complete feasible domain of all networks. Additionally, each network generator covers its own network-specific domain and, consequently, contributes to the generation of data sets. Secondly, we perform computational results on the well-known resource-constrained project scheduling problem to prove that our indicators are reliable and have significant, predictive power to serve as complexity indicators.

Maybe stories are just data with a
soul.
Brene Brown



The impact of various activity assumptions on the lead time and resource utilization of resource-constrained projects

Vanhoucke, Mario; Debels, Dieter

Tags

branch-and-bound; fast tracking; preemption; project management; resource constrained project scheduling

Reference

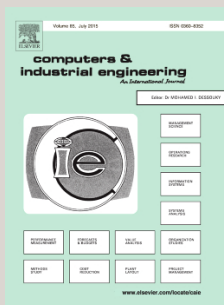
Vanhoucke, M. and Debels, D. (2008). The impact of various activity assumptions on the lead time and resource utilization of resource-constrained projects. *Computers & Industrial Engineering*, 54:140–154

DOI

10.1016/j.cie.2007.07.001

Classification

International peer-reviewed journal; Written for researchers and professionals



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Activity assumptions

The well-known resource-constrained project scheduling problem (RCPSP) schedules project activities within the precedence and renewable resource constraints while minimizing the total lead time of the project. The basic problem description assumes non-pre-emptive activities with fixed durations, and has been extended to various other assumptions in the literature. In this paper, we investigate the effect of three activity assumptions on the total lead time and the total resource utilization of a project. More precisely, we investigate the influence of variable activity durations under a fixed work content, the possibility of allowing activity pre-emption and the use of fast tracking to decrease a project's duration. We give an overview of the procedures developed in the literature and present some modifications to an existing solution approach to cope with our activity assumptions under study. We present computational results on a generated dataset and evaluate the impact of all assumptions on the quality of the schedule.

*Better three hours too soon than a
minute too late.
William Shakespeare*



Setup times and fast tracking in resource-constrained project scheduling

Vanhoucke, Mario

Tags

branch-and-bound; preemption;
project management; resource
constrained project scheduling

Reference

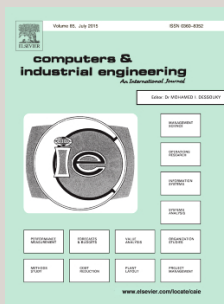
Vanhoucke, M. (2008). Setup times and fast tracking in resource-constrained project scheduling. *Computers & Industrial Engineering*, 54:1062–1070

DOI

10.1016/j.cie.2007.11.008

Classification

International peer-reviewed journal; Written for researchers



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Fast tracking

Resource-constrained project scheduling with activity pre-emption assumes that activities are allowed to be interrupted and restarted later in the schedule at no extra cost. In the current paper, we extend this pre-emptive scheduling problem with setup times between activity interruptions and the possibility to schedule pre-emptive sub-parts of activities in parallel. The contribution of the paper is twofold. First, we briefly show that an efficient exact branch-and-bound procedure from the literature to solve the resource-constrained project scheduling problem can be easily adapted to cope with our problem extensions. Second, we extensively test the impact of these pre-emptive extensions to the quality of the schedule from a makespan point-of-view.

*Design is not just what it looks
like and feels like. Design is how it
works.*
Steve Jobs



A decomposition-based genetic algorithm for the resource-constrained project-scheduling problem

Debels, Dieter; Vanhoucke, Mario

Tags

decomposition; genetic algorithm; meta-heuristics; project management; resource constrained project scheduling

Reference

Debels, D. and Vanhoucke, M. (2007). A decomposition-based genetic algorithm for the resource-constrained project scheduling problems. *Operations Research*, 55:457–469

DOI

10.1287/opre.1060.0358

Classification

International peer-reviewed journal; Written for researchers



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Decomposed resource scheduling

In the last few decades, the resource-constrained project-scheduling problem has become a popular problem type in operations research. However, due to its strongly NP-hard status, the effectiveness of exact optimisation procedures is restricted to relatively small instances. In this paper, we present a new genetic algorithm (GA) for this problem that is able to provide near-optimal heuristic solutions. This GA procedure has been extended by a so-called decomposition-based genetic algorithm (DBGA) that iteratively solves subparts of the project. We present computational experiments on two data sets. The first benchmark set is used to illustrate the performance of both the GA and the DBGA. The second set is used to compare the results with current state-of-the-art heuristics and to show that the procedure is capable of producing consistently good results for challenging problem instances. We illustrate that the GA outperforms all state-of-the-art heuristics and that the DBGA further improves the performance of the GA.

*Research is to see what everybody
else has seen, and to think what
nobody else has thought.*
Albert Szent-Gyorgyi



A simulation analysis of interactions among errors in costing systems

Labro, Eva; Vanhoucke, Mario

Tags

activity based costing; management accounting; simulation

Reference

Labro, E. and Vanhoucke, M. (2007). A simulation analysis of interactions among errors in costing system designs. *The Accounting Review*, 82:939–962

DOI

10.2308/accr.2007.82.4.939

Classification

International peer-reviewed journal; Written for researchers and professionals



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Errors in costing systems

Cost accounting systems provide accurate costs only under stringent conditions. However, we know little about the nature, level, and bias of costing errors. This paper reports the results of a simulation study of two-stage cost allocation systems that provide the following main insights: (1) partial improvement in the costing system usually increases the overall accuracy of reported product costs except in specific cases identified in this paper where errors have an offsetting effect, most notably when there is aggregation error in the activity cost pools and measurement error in the resource drivers; (2) the impact of Stage II costing errors on overall accuracy is stronger than that of Stage I errors, so system refinements should focus on Stage II; and (3) the presence of aggregation and measurement errors usually results in relatively more products being under- than over-costed, with large amounts of over-costing for a few “big-ticket” (in dollar terms) products, and small amounts of under-costing for a larger number of less expensive products.

We really can't forecast all that well, and yet we pretend that we can, but we really can't.
Alan Greenspan



An electromagnetic meta-heuristic for the nurse scheduling problem

Maenhout, Broos; Vanhoucke, Mario

Tags

Electromagnetic Meta-heuristic;
health; healthcare scheduling;
meta-heuristic; nurse scheduling

Reference

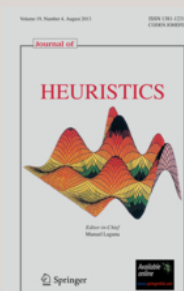
Maenhout, B. and Vanhoucke, M. (2007). An electromagnetic meta-heuristic for the nurse scheduling problem. *Journal of Heuristics*, 13:359–385

DOI

10.1007/s10732-007-9013-7

Classification

International peer-reviewed journal; Written for researchers



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Electromagnetic nurse scheduling

In this paper, we present a novel meta-heuristic technique for the nurse scheduling problem (NSP). This well-known scheduling problem assigns nurses to shifts per day maximizing the overall quality of the roster while taking various constraints into account. The problem is known to be NP-hard. Due to its complexity and relevance, many algorithms have been developed to solve practical and often case-specific models of the NSP. The huge variety of constraints and the several objective function possibilities have led to exact and meta-heuristic procedures in various guises, and hence comparison and state-of-the-art reporting of standard results seem to be a utopian idea. We present a meta-heuristic procedure for the NSP based on the framework proposed by Birbil and Fang (*J. Glob. Opt.* 25, 263-282, 2003). The Electromagnetic (EM) approach is based on the theory of physics, and simulates attraction and repulsion of sample points in order to move towards a promising solution. Moreover, we present computational experiments on a standard benchmark dataset, and solve problem instances under different assumptions. We show that the proposed procedure performs consistently well under many different circumstances, and hence, can be considered as robust against case-specific constraints.

The toughest thing about managing is knowing your personnel and what it can give you under all conditions.
Walter Alston



A simulation and evaluation of earned value metrics to forecast the project duration

Vanhoucke, Mario; Vandevorde, Stephan

Tags

earned schedule; earned value management; forecasting; project control; project management; simulation

Reference

Vanhoucke, M. and Vandevorde, S. (2007). A simulation and evaluation of earned value metrics to forecast the project duration. *Journal of the Operational Research Society*, 58:1361–1374

DOI

10.1016/j.ijproman.2005.10.004

Classification

International peer-reviewed journal; Written for researchers and professionals



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Evaluating earned value

In this paper, we extensively review and evaluate earned value (EV)-based methods to forecast the total project duration. EV systems have been set up to deal with the complex task of controlling and adjusting the baseline project schedule during execution, taking into account project scope, timed delivery and total project budget. Although EV systems have been proven to provide reliable estimates for the follow-up of cost performance within our project assumptions, they often fail to predict the total duration of the project. We present an extensive simulation study where we carefully control the level of uncertainty in the project, the influence of the project network structure on the accuracy of the forecasts and the time horizon where the EV-based measures provide accurate and reliable results. We assume a project setting where project activities and precedence relations are known in advance and do not consider fundamentally unforeseeable events and/or unknown interactions among various actions that might cause entirely unexpected effects in different project parts. This is the first study that investigates the potential of a recently developed method, the earned schedule method, which improves the connection between EV metrics and the project duration forecasts.

By three methods we may learn wisdom: First, by reflection, which is noblest; Second, by imitation, which is easiest; and third by experience, which is the bitterest.
Confucius



The discrete time/cost trade-off problem: extensions and heuristic procedures

Vanhoucke, Mario; Debels, Dieter

Tags

benders decomposition; branch-and-bound; meta-heuristic; net present value; project management; project scheduling; tabu search; time-switch constraints; time/cost trade-off problem; work continuity

Reference

Vanhoucke, M. and Debels, D. (2007). The discrete time/cost trade-off problem: Extensions and heuristic procedures. *Journal of Scheduling*, 10:311–326

DOI

10.1007/s10951-007-0031-y

Classification

International peer-reviewed journal; Written for researchers



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Time/cost extensions

Time/cost trade-offs in project networks have been the subject of extensive research since the development of the critical path method (CPM) in the late 50s. Time/cost behaviour in a project activity basically describes the tradeoff between the duration of the activity and its amount of non-renewable resources (e.g., money) committed to it. In the discrete version of the problem (the discrete time/cost trade-off problem), it is generally accepted that the trade-off follows a discrete non-increasing pattern, i.e., expediting an activity is possible by allocating more resources (i.e., at a larger cost) to it. However, due to its complexity, the problem has been solved for relatively small instances. In this paper we elaborate on three extensions of the well-known discrete time/cost trade-off problem in order to cope with more realistic settings: time/switch constraints, work continuity constraints, and net present value maximization. We give an extensive literature overview of existing procedures for these problem types and discuss a new meta-heuristic approach in order to provide near-optimal heuristic solutions for the different problems. We present computational results for the problems under study by comparing the results for both exact and heuristic procedures. We demonstrate that the heuristic algorithms produce consistently good results for two versions of the discrete time/cost trade-off problem.

The latest scientific assessment has almost doubled the predicted rate of warming if no changes are made.
Donella Meadows



Work continuity optimization for the Westerscheldetunnel project in the Netherlands

Vanhoucke, Mario

Tags

case study; project management; project scheduling; recursive search; work continuity

Reference

Vanhoucke, M. (2007). Work continuity optimization for the Westerscheldetunnel project in the Netherlands. *Tijdschrift voor Economie en Management*, 52:435–449

DOI

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Classification

International peer-reviewed journal; Written for researchers and professionals



Westerschelde tunnel

The scheduling of projects has gained increasing attention since the introduction of PERT and CPM. Both the scheduling literature and the software scheduling packages rely on (meta-)heuristic and exact procedures to schedule projects under various assumptions. However, there is still room for improvement by incorporating specific characteristics into the scheduling procedures. In this paper we describe the scheduling of a real-life project that aims at the construction of a tunnel at the Westerschelde in the Netherlands. In doing so, we show that so-called work continuity is the main issue during the scheduling phase. No software package, however, is able to incorporate this requirement in an exact way. We compare different possible schedules under various assumptions and prove the necessity of this new feature.

Change is the end result of all true learning.
Leo Buscaglia



A hybrid scatter search/electromagnetism meta-heuristic for project scheduling

Debels, Dieter; De Reyck, Bert; Leus, Roel; Vanhoucke, Mario

Tags

electromagnetism; meta-heuristics; project management; resource constrained project scheduling; scatter search

Reference

Debels, D., De Reyck, B., Leus, R., and Vanhoucke, M. (2006). A hybrid scatter search/electromagnetism meta-heuristic for project scheduling. *European Journal of Operational Research*, 169:638–653

DOI

10.1016/j.ejor.2004.08.020

Classification

International peer-reviewed journal; Written for researchers



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Electromagnetic search

In the last few decades, several effective algorithms for solving the resource-constrained project scheduling problem have been proposed. However, the challenging nature of this problem, summarised in its strongly NP-hard status, restricts the effectiveness of exact optimisation to relatively small instances. In this paper, we present a new meta-heuristic for this problem, able to provide near-optimal heuristic solutions for relatively large instances. The procedure combines elements from scatter search, a generic population-based evolutionary search method, and from a recently introduced heuristic method for the optimisation of unconstrained continuous functions based on an analogy with electromagnetism theory. We present computational experiments on standard benchmark datasets, compare the results with current state-of-the-art heuristics, and show that the procedure is capable of producing consistently good results for challenging instances of the resource-constrained project scheduling problem. We also demonstrate that the algorithm outperforms state-of-the-art existing heuristics.

In so far as a scientific statement speaks about reality, it must be falsifiable; and in so far as it is not falsifiable, it does not speak about reality.
Karl Popper



The electromagnetism meta-heuristic applied to the resource-constrained project scheduling problem

Debels, Dieter; Vanhoucke, Mario

Tags

electromagnetism; meta-heuristics; project management; resource constrained project scheduling

Reference

Debels, D. and Vanhoucke, M. (2006). The electromagnetism meta-heuristic applied to the resource-constrained project scheduling problems. *Lecture Notes in Computer Science*, 3871:259–270

DOI

10.1007/11740698_23

Classification

International peer-reviewed journal; Written for researchers



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Decomposing problems

Recently, an electromagnetism (EM) heuristic has been introduced by Birbil and Fang (2003) to solve unconstrained optimization problems. In this paper, we extend the EM methodology to combinatorial optimization problems and illustrate its effectiveness on the well-known resource-constrained project scheduling problem (RCPSP). We present computational experiments on a standard benchmark dataset, compare the results of the different modifications on the original EM framework with current state-of-the-art heuristics, and show that the procedure is capable of producing consistently good results for challenging instances of the problem under study. We also give directions for future research in order to further explore the potential of this new technique.

Nature doesn't feel compelled to stick to a mathematically precise algorithm; in fact, nature probably can't stick to an algorithm.
Margaret Wertheim



New computational results for the nurse scheduling problem: A scatter search algorithm

Maenhout, Broos; Vanhoucke, Mario

Tags

healthcare scheduling; meta-heuristic; nurse scheduling; personnel scheduling; scatter search

Reference

Maenhout, B. and Vanhoucke, M. (2006). New computational results for the nurse scheduling problem: A scatter search algorithm. *Lecture Notes in Computer Science*, 3906:159–170

DOI

10.1007/11730095_14

Classification

International peer-reviewed journal; Written for researchers



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Nurse scheduling

In this paper, we present a scatter search algorithm for the well-known nurse scheduling problem (NSP). This problem aims at the construction of roster schedules for nurses taking both hard and soft constraints into account. The objective is to minimize the total preference cost of the nurses and the total penalty cost from violations of the soft constraints. The problem is known to be NP-hard. The contribution of this paper is threefold. First, we are, to the best of our knowledge, the first to present a scatter search algorithm for the NSP. Second, we investigate two different types of solution combination methods in the scatter search framework, based on four different cost elements. Last, we present detailed computational experiments on a benchmark dataset presented recently, and solve these problem instances under different assumptions. We show that our procedure performs consistently well under many different circumstances, and hence, can be considered as robust against case-specific constraints.

*Life is made up of a series of
judgments on insufficient data,
and if we waited to run down all
our doubts, it would flow past us.*
Learned Hand



A comparison of different project duration forecasting methods using earned value metrics

Vandevoorde, Stephan; Vanhoucke, Mario

Tags

case study; earned schedule;
earned value management;
forecasting; project management

Reference

Vandevoorde, S. and Vanhoucke, M. (2006). A comparison of different project duration forecasting methods using earned value metrics. *International Journal of Project Management*, 24:289–302

DOI

10.1016/j.ijproman.2005.10.004

Classification

International peer-reviewed journal; Written for researchers and professionals



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Comparing earned value

Earned value project management is a well-known management system that integrates cost, schedule and technical performance. It allows the calculation of cost and schedule variances and performance indices and forecasts of project cost and schedule duration. The earned value method provides early indications of project performance to highlight the need for eventual corrective action. Earned value management was originally developed for cost management and has not widely been used for forecasting project duration. However, recent research trends show an increase of interest to use performance indicators for predicting total project duration. In this paper, we give an overview of the state-of-the-art knowledge for this new research trend to bring clarity in the often confusing terminology. The purpose of this paper is 3-fold. First, we compare the classic earned value performance indicators SV and SPI with the newly developed earned schedule performance indicators SV(t) and SPI(t). Next, we present a generic schedule forecasting formula applicable in different project situations and compare the three methods from literature to forecast total project duration. Finally, we illustrate the use of each method on a simple one activity example project and on real-life project data.

*There is no comparison between
that which is lost by not
succeeding and that which is lost
by not trying.*
Francis Bacon



An efficient hybrid search algorithm for various optimization problems

Vanhoucke, Mario

Tags

cash flows; net present value; project management; project scheduling; recursive algorithm

Reference

Vanhoucke, M. (2006). An efficient hybrid search algorithm for various optimization problems. *Lecture Notes in Computer Science*, 3906:272–283

DOI

10.1007/11730095_23

Classification

International peer-reviewed journal; Written for researchers



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Hybrid search algorithms

This paper describes a detailed study of a recursive search algorithm for different optimization problems. Although the algorithm has been originally developed for a project scheduling problem with financial objectives, we show that it can be extended to many other application areas and therefore, can serve as a sub-procedure for various optimization problems. The contribution of the paper is threefold. First, we present a hybrid recursive search procedure for the project scheduling problem with net present value maximization and compare it with state-of-the-art procedures by means of computational tests. Second, we show how the procedure can be adapted to two other application areas: project scheduling with work continuity minimization and the open pit mining problem. Last, we highlight some future research areas where this hybrid procedure might bring a promising contribution.

Scientific progress makes moral progress a necessity; for if man's power is increased, the checks that restrain him from abusing it must be strengthened.
Madame de Stael



Work continuity constraints in project scheduling

Vanhoucke, Mario

Tags

case study; project management;
project scheduling; recursive
algorithm; work continuity

Reference

Vanhoucke, M. (2006). Work continuity constraints in project scheduling. *Journal of Construction Engineering and Management*, 132:14–25

DOI

10.1061/(ASCE)0733-9364(2006)132:1(14)

Classification

International peer-reviewed journal;
Written for researchers and professionals



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Work continuity constraints

Repetitive projects involve the repetition of activities along the stages of the project. Since the resources required to perform these activities move from one stage to the other, a main objective of scheduling these projects is to maintain the continuity of work of these resources so as to minimize the idle time of resources. This requirement, often referred to as work continuity constraints, involves a tradeoff between total project duration and the resource idle time. The contribution of this paper is threefold. First, we provide an extensive literature summary of the topic under study. Although most research papers deal with the scheduling of construction projects, we show that this can be extended to many other environments. Second, we propose an exact search procedure for scheduling repetitive projects with work continuity constraints. This algorithm iteratively shifts repeating activities further in time in order to decrease the resource idle time. We have embedded this recursive search procedure in a horizon-varying algorithm in order to detect the complete tradeoff profile between resource idle time and project duration. The procedure has been coded in Visual C++ and has been validated on a randomly generated problem set. Finally, we illustrate the concepts on three examples. First, the use of our new algorithm is illustrated on a small fictive problem example from literature. In a second example, we show that work continuity constraints involve a tradeoff between total project duration and the resource idle time. A last example describes the scheduling of a well-known real-life project that aims at the construction of a tunnel at the Westerschelde in The Netherlands.

*No sensible decision can be made
any longer without taking into
account not only the world as it is,
but the world as it will be.*
Isaac Asimov



Scheduling an R&D project with quality-dependent time slots

Vanhoucke, Mario

Tags

branch-and-bound; project management; quality-dependent time slots; resource constrained project scheduling

Reference

Vanhoucke, M. (2006). Scheduling an R&D project with quality-dependent time slots. *Lecture Notes in Computer Science*, 3982:621–630

DOI

10.1007/11751595_66

Classification

International peer-reviewed journal; Written for researchers



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Quality dependent time slots

In this paper we introduce the concept of quality-dependent time slots in the project scheduling literature. Quality-dependent time slots refer to pre-defined time windows where certain activities can be executed under ideal circumstances (optimal level of quality). Outside these time windows, there is a loss of quality due to detrimental effects. The purpose is to select a quality-dependent time slot for each activity, resulting in a minimal loss of quality. The contribution of this paper is threefold. First, we show that an R&D project from the bio-technology sector can be transformed to a resource-constrained project scheduling problem (RCPSP). Secondly, we propose an exact search procedure for scheduling this project with the aforementioned quality restrictions. Finally, we test the performance of our procedure on a randomly generated problem set.

Be a yardstick of quality. Some people aren't used to an environment where excellence is expected.
Steve Jobs



A bi-population based genetic algorithm for the resource-constrained project scheduling problem

Debels, Dieter; Vanhoucke, Mario

Tags

genetic algorithm; meta-heuristics; project management; resource constrained project scheduling

Reference

Debels, D. and Vanhoucke, M. (2005). A bi-population based genetic algorithm for the resource-constrained project scheduling problem. *Lecture Notes in Computer Science*, 3483:378–387

DOI

10.1007/11424925_41

Classification

International peer-reviewed journal; Written for researchers



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Bi-population genetic algorithm

The resource-constrained project scheduling problem (RCPSP) is one of the most challenging problems in project scheduling. During the last couple of years many heuristic procedures have been developed for this problem, but still these procedures often fail in finding near-optimal solutions for more challenging problem instances. In this paper, we present a new genetic algorithm (GA) that, in contrast of a conventional GA, makes use of two separate populations. This bi-population genetic algorithm (BPGA) operates on both a population of left-justified schedules and a population of right-justified schedules in order to fully exploit the features of the iterative forward/backward scheduling technique. Comparative computational results reveal that this procedure can be considered as today's best performing RCPSP heuristic.

*I work out like a maniac and I
spray tan a lot. Genetics were
kind, but I work very hard.*
Anna Paquin



The project scheduling game (PSG): simulating time/cost trade-offs in projects

Vanhoucke, Mario; Vereecke, Ann; Gemmel, Paul

Tags

business game; project management; project scheduling; time/cost trade-off problem

Reference

Vanhoucke, M., Vereecke, A., and Gemmel, P. (2005). The project scheduling game (PSG): Simulating time/cost trade-offs in projects. *Project Management Journal*, 36:51–59

URL

www.pmi.org

Classification

International peer-reviewed journal; Written for students and professionals; More information available at www.protrack.be/psg



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Project scheduling game

The project scheduling game (PSG) is an IT-supported simulation that illustrates the complexity of scheduling sequences of activities for real-life projects. Focusing on PSG as an educational tool, the authors explain how it supported the realization of a massive water purification project at a Belgium water distribution company, Vlaamse Maatschappij voor Watervoorziening. In examining this project, the authors used as their basic approach a critical path method (CPM) network problem; they also analyzed the time and cost relationship for each activity performed during this project. The authors additionally explain the different features of PSG as well as the three parts of the traditional PSG session and the approach for teaching this process and evaluating the performance of teams that use PSG.

A student should be an active participant, not a passive consumer.
Bell Hooks



New computational results for the discrete time/cost trade-off problem with time-switch constraints

Vanhoucke, Mario

Tags

branch-and-bound; project management; project scheduling; time-switch constraints; time/cost trade-off problem

Reference

Vanhoucke, M. (2005). New computational results for the discrete time/cost trade-off problem with time-switch constraints. *European Journal of Operational Research*, 165:359–374

DOI

10.1016/j.ejor.2004.04.007

Classification

International peer-reviewed journal; Written for researchers



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Time-switch constraints II

Recently, time-switch constraints have been introduced in the literature by Yang and Chen [Eur. J. Operat. Res. 120 (2000) 603]. Basically, these constraints impose a specified starting time on the project activities and force them to be inactive during specified time periods. This type of constraints have been incorporated into the well-known discrete time/cost trade-off problem in order to cope with day, night and weekend shifts. In this paper, we propose a new branch-and-bound algorithm which outperforms the previous one by Vanhoucke et al. [J. Operat. Res. Soc. 53 (2002) 1]. The procedure makes use of a lower bound calculation for the discrete time/cost trade-off problem (without time-switch constraints). The procedure has been coded in Visual C++, version 6.0 under Windows 2000 and has been validated on a randomly generated problem set.

The question of whether a computer can think is no more interesting than the question of whether a submarine can swim.
Edsger W. Dijkstra



RanGen: A random network generator for activity-on-the-node networks

Demeulemeester, Erik; Vanhoucke, Mario; Herroelen, Willy

Tags

artificial data; data generator;
network analysis; project
management; resource analysis

Reference

Demeulemeester, E., Vanhoucke, M., and Herroelen, W. (2003). RanGen: A random network generator for activity-on-the-node networks. *Journal of Scheduling*, 6:17–38

DOI

10.1023/A:1022283403119

Classification

International peer-reviewed journal; Written for researchers; Project network generator available at www.projectmanagement.ugent.be



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Generating networks I

In this paper, we describe RanGen, a random network generator for generating activity-on-the-node networks and accompanying data for different classes of project scheduling problems. The objective is to construct random networks which satisfy preset values of the parameters used to control the hardness of a problem instance. Both parameters which are related to the network topology and resource-related parameters are implemented. The network generator meets the shortcomings of former network generators since it employs a wide range of different parameters which have been shown to serve as possible predictors of the hardness of different project scheduling problems. Some of them have been implemented in former network generators while others have not.

*It is a capital mistake to theorize
before one has data.*
Arthur Conan Doyle



Progress payments in project scheduling problems

Vanhoucke, Mario; Demeulemeester, Erik; Herroelen, Willy

Tags

branch-and-bound; cash flows; earliness/tardiness; net present value; project management; resource constrained project scheduling

Reference

Vanhoucke, M., Demeulemeester, E., and Herroelen, W. (2003). Progress payments in project scheduling problems. *European Journal of Operational Research*, 148:604–620

DOI

10.1016/S0377-2217(02)00452-6

Classification

International peer-reviewed journal; Written for researchers

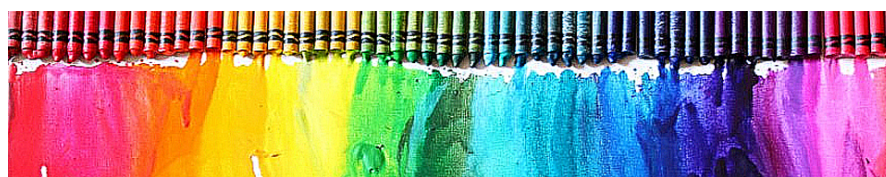


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Progress payments

In this paper we study the unconstrained project scheduling problem with discounted cash flows where the net cash flows are assumed to be dependent on the completion times of the corresponding activities. Cash outflows occur when an activity is completed whereas cash inflows are incurred as progress payments at the end of some time period. The objective is to schedule the activities in order to maximize the net present value of the project subject to the precedence constraints and a fixed deadline. This paper extends the ever-growing amount of research concerning the financial aspects in project scheduling in which cash flows are time-dependent. We introduce a branch-and-bound algorithm which computes upper bounds by making piecewise linear overestimations. In doing so, the algorithm transforms the problem into a weighted earliness-tardiness project scheduling problem. The algorithm is extended with two new rules in order to reduce the size of the branch-and-bound tree. Computational results are reported.

*If you think nobody cares about
you, try missing a couple of
payments.*
Steven Wright



The application of project scheduling techniques in a real-life environment

Vanhoucke, Mario; Demeulemeester, Erik

Tags

case study; cash flows; net present value; project management; project scheduling; recursive algorithm

Reference

Vanhoucke, M. and Demeulemeester, E. (2003). The application of project scheduling techniques in a real-life environment. *Project Management Journal*, 34:30–42

URL

www.pmi.org

Classification

International peer-reviewed journal; Written for students, researchers and professionals



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Water production scheduling

The scheduling of activities over time has gained increasing attention with the development of the critical path method (CPM) and the program evaluation and review technique (PERT). Since then, a large amount of solution procedures for a wide range of problem types have been proposed in the literature. Many of these procedures, however, are not able to solve real-life problems. In this paper we describe a capacity expansion project at a water production center (WPC) of the Vlaamse Maatschappij voor Watervoorziening VMW) in Belgium. This project aims at expanding the production capacity of pure water. We show that scheduling the project with certain techniques will improve the financial status of the project. We illustrate this statement with different schedules.

The important thing is not to stop questioning. Curiosity has its own reason for existing.
Albert Einstein



Discrete time/cost trade-offs in project scheduling with time-switch constraints

Vanhoucke, Mario; Demeulemeester, Erik; Herroelen, Willy

Tags

branch-and-bound; project management; project scheduling; time-switch constraints; time/cost trade-off problem

Reference

Vanhoucke, M., Demeulemeester, E., and Herroelen, W. (2002). Discrete time/cost trade-offs in project scheduling with time-switch constraints. *Journal of the Operational Research Society*, 53:741–751

DOI

10.1057/palgrave.jors.2601351

Classification

International peer-reviewed journal; Written for researchers



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Time-switch constraints I

The discrete time/cost trade-off problem assumes the duration of project activities to be discrete, non-increasing functions of the amount of a single non-renewable resource. The problem has been studied under three possible objectives. The so-called deadline problem involves the scheduling of project activities in order to minimize the total cost of the project while meeting a given deadline. The budget problem aims at minimizing the project duration without exceeding a given budget. A third objective involves the generation of the complete efficient time/cost profile over the set of feasible project durations. In this paper we describe a solution procedure for the deadline problem in which three special cases of time-switch constraints are involved. These constraints impose a specified starting time on the project activities and force them to be inactive during specified time periods. We propose a branch-and-bound algorithm and a heuristic procedure which both make use of a lower bound calculation for the discrete time/cost trade-off problem (without time-switch constraints). The procedures have been coded in Visual C++, version 6.0 under Windows 2000 and have been validated on a randomly generated problem set. We also discuss an illustrative example based on a real-life situation.

*Teach us to give and not to count
the cost.
Saint Ignatius*



Maximizing the net present value of a project with linear time-dependent cash flows

Vanhoucke, Mario; Demeulemeester, Erik; Herroelen, Willy

Tags

cash flows; net present value; project management; project scheduling; recursive algorithm

Reference

Vanhoucke, M., Demeulemeester, E., and Herroelen, W. (2001). Maximizing the net present value of a project with linear time-dependent cash flows. *International Journal of Production Research*, 39:3159–3181

DOI

10.1080/00207540110056919

Classification

International peer-reviewed journal; Written for researchers



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Linear time dependencies

The paper studies the unconstrained project-scheduling problem with discounted cashflows where the cashflow functions are assumed to be linear-dependent on the completion times of the corresponding activities. Each activity of this unconstrained project scheduling problem has a known deterministic cashflow function that is linear and non-increasing in time. Progress payments and cash outflows occur at the completion times of activities. The objective is to schedule the activities in order to maximize the net present value (npv) subject to the precedence constraints and a fixed deadline. Despite the growing amount of research concerning the financial aspects in project scheduling, little research has been done on the problem with time-dependent cashflow functions. Nevertheless, this problem gives an incentive to solve more realistic versions of project-scheduling problems with financial objectives. We introduce an extension of an exact recursive algorithm that has been used in solving the max-npv problem with time-independent cashflow functions and which is embedded in an enumeration procedure. The recursive search algorithm schedules the activities as soon as possible and searches for sets of activities to shift towards the deadline in order to increase the npv. The enumeration procedure enumerates all sets of activities for which such a shift has not been made but could, eventually, have been advantageous. The procedure has been coded in Visual C++ v.4.0 under Windows NT and has been validated on a randomly generated problem set.

The fact is that one of the earliest lessons I learned in business was that balance sheets and income statements are fiction, cash flow is reality.
Chris Chocola



On maximizing the net present value of a project under renewable resource constraints

Vanhoucke, Mario; Demeulemeester, Erik; Herroelen, Willy

Tags

branch-and-bound; cash flows;
net present value; project management;
resource constrained
project scheduling

Reference

Vanhoucke, M., Demeulemeester, E., and Herroelen, W. (2001). On maximizing the net present value of a project under renewable resource constraints. *Management Science*, 47:1113–1121

DOI

10.1287/mnsc.47.8.1113.10226

Classification

International peer-reviewed journal; Written for researchers; Data and solutions available at www.projectmanagement.ugent.be



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Net present value

In this paper we study the resource-constrained project-scheduling problem with discounted cash flows. Each activity of this resource-constrained project-scheduling problem has certain resource requirements and a known deterministic cash flow that can be either positive or negative. Deterministic cash flows are assumed to occur over the duration of the activities. Progress payments and cash outflows occur at the completion of activities. The objective is to schedule the activities subject to a fixed deadline to maximize the net present value subject to the precedence and resource constraints. With these features the financial aspects of project management are taken into account. We introduce a depth-first branch-and-bound algorithm that makes use of extra precedence relations to resolve a number of resource conflicts and a fast recursive search algorithm for the max-npv problem to compute upper bounds. The recursive search algorithm exploits the idea that positive cash flows should be scheduled as early as possible while negative cash flows should be scheduled as late as possible within the precedence constraints. The procedure has been coded in Visual C++, Version 4.0 under Windows NT, and has been validated on two problem sets.

*Life is like a cash register, in that
every account, every thought,
every deed, like every sale, is
registered and recorded.*
Fulton J. Sheen



An exact procedure for the resource-constrained weighted earliness-tardiness project scheduling problem

Vanhoucke, Mario; Demeulemeester, Erik; Herroelen, Willy

Tags

branch-and-bound; earliness/tardiness; project management; resource constrained project scheduling

Reference

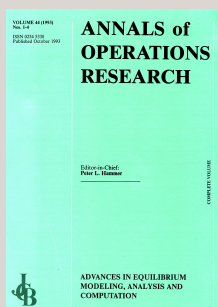
Vanhoucke, M., Demeulemeester, E., and Herroelen, W. (2001). An exact procedure for the resource-constrained weighted earliness-tardiness project scheduling problem. *Annals of Operations Research*, 102:179–196

DOI

10.1023/A:1010958200070

Classification

International peer-reviewed journal; Written for researchers



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Earliness/tardiness

In this paper we study the resource-constrained project scheduling problem with weighted earliness-tardiness penalty costs. Project activities are assumed to have a known deterministic due date, a unit earliness as well as a unit tardiness penalty cost and constant renewable resource requirements. The objective is to schedule the activities in order to minimize the total weighted earliness-tardiness penalty cost of the project subject to the finish-start precedence constraints and the constant renewable resource availability constraints. With these features the problem becomes highly attractive in just-in-time environments. We introduce a depth-first branch-and-bound algorithm which makes use of extra precedence relations to resolve resource conflicts and relies on a fast recursive search algorithm for the unconstrained weighted earliness-tardiness problem to compute lower bounds. The procedure has been coded in Visual C++, version 4.0 under Windows NT. Both the recursive search algorithm and the branch-and-bound procedure have been validated on a randomly generated problem set.

*Stay committed to your decisions,
but stay flexible in your approach.*
Tony Robbins



New computational results on the discrete time/cost trade-off problem in project networks

Demeulemeester, Erik; De Reyck, Bert; Foubert, Bram; Herroelen, Willy; Vanhoucke, Mario

Tags

branch-and-bound; lower bound;
project management; project
scheduling; time/cost trade-off

Reference

Demeulemeester, E., De Reyck, B., Foubert, B., Herroelen, W., and Vanhoucke, M. (1998). New computational results on the discrete time/cost trade-off problem in project networks. *Journal of the Operational Research Society*, 49:1153–1163

DOI

10.1057/palgrave.jors.2600634

Classification

International peer-reviewed journal; Written for researchers



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Time/cost optimization

We describe a new exact procedure for the discrete time/cost trade-off problem in deterministic activity-on-the-arc networks of the CPM type, where the duration of each activity is a discrete, nonincreasing function of the amount of a single resource (money) committed to it. The objective is to construct the complete and efficient time/cost profile over the set of feasible project durations. The procedure uses a horizon-varying approach based on the iterative optimal solution of the problem of minimising the sum of the resource use over all activities subject to the activity precedence constraints and a project deadline. This optimal solution is derived using a branch-and-bound procedure which computes lower bounds by making convex piecewise linear underestimations of the discrete time/cost trade-off curves of the activities to be used as input for an adapted version of the Fulkerson labelling algorithm for the linear time/cost trade-off problem. Branching involves the selection of an activity in order to partition its set of execution modes into two subsets which are used to derive improved convex piecewise linear underestimations. The procedure has been programmed in Visual C++ under Windows NT and has been validated using a factorial experiment on a large set of randomly generated problem instances.

*My favorite things in life don't
cost any money. It's really clear
that the most precious resource we
all have is time.*
Steve Jobs



Part II

Professional articles

Introdução à duração agregada

André, Paulo; Vanhoucke, Mario; Salvaterra, Floriano

Tags

earned schedule; earned value management; project control; project management

Reference

André, P., Vanhoucke, M., and Salvaterra, F. (2015). Introdução à duração agregada. *Mundo Project Management*, 62:56–65

URL

www.mundopm.com.br

Classification

Professional magazine; Written for professionals

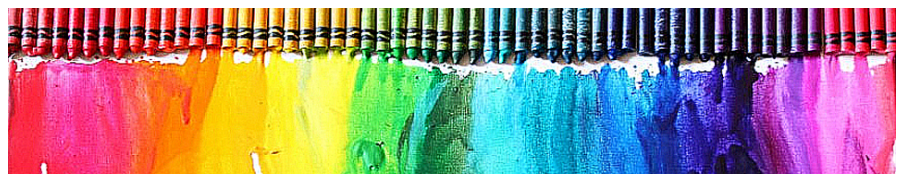


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Duração agregada

O gerenciamento de prazos em projeto evoluiu significativamente desde o desenvolvimento do Gráfico de Gantt no começo do século 20 (Gantt, 1919), do PERT/CPM (Program Evaluation and Review Technique/Critical Path Method, 1958), do Método do Diagrama de Precedência em meados do século passado (Fondahl, 1987) e da CCPM (Critical Chain Project Management, Goldratt, 2002). A evolução dos microcomputadores e seus softwares facilitou o uso e a popularização dessas técnicas na gestão de projetos.

*In much of society, research means
to investigate something you do
not know or understand.*
Neil Armstrong



Classroom experiments on project management communication

Vanhoucke, Mario; Wauters, Mathieu

Tags

blended learning; project management

Reference

Vanhoucke, M. and Wauters, M. (2015). Classroom experiments on project management communication. *The Measurable News*, 4:29–33

URL

www.mycpm.org

Classification

Professional magazine; Written for professionals



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Communication experiments

This manuscript gives a brief overview of three sets of experiments in the classroom with students following a Project Management (PM) course module using a blended learning approach. The impact of communication on the student performance using business games as well as the advantages of the use of integrative case studies and their impact on the learning experience of these students are tested. The performance of students is measured by their quantitative output on the business game or case exercise, while their learning experience is measured by the student evaluations. The experiments have been carried out on a sample of students with a different background, ranging from university students with or without a strong quantitative background but no practical experience, to MBA students at business schools and PM professionals participating in a PM training. The results have been presented at an international workshop on computer supported education in Lisbon (Portugal) in 2015 and details have been published in Vanhoucke and Wauters (2015).

The single biggest problem in communication is the illusion that it has taken place.
George Bernard Shaw



Introduction to earned duration

Vanhoucke, Mario; André, Paulo; Salvaterra, Floriano; Batselier, Jordy

Tags

earned schedule; earned value management; project control; project management

Reference

Vanhoucke, M. (2015). Introduction to earned duration. *The Measurable News*, 2:15–27

URL

www.mycpm.org

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Professional magazine; Written for professionals



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Earned duration

The management of project baseline schedules has evolved significantly since the development of the Gantt chart in the early 20th century (Gantt, 1919). In the next few decennia, the Program Evaluation and Review Technique/Critical Path Method and the Precedence Diagram Method (Fondahl, 1987), and more recently, the Critical Chain Project Management technique (Goldratt, 2002) saw the light.

*If your experiment needs statistics,
you ought to have done a better
experiment.*
Ernest Rutherford



Gerenciamento integrado de controles de projetos: Primeiro vem a teoria, e então a prática

Vanhoucke, Mario

Tags

earned schedule; earned value management; forecasting; project control; project management; schedule risk analysis

Reference

Vanhoucke, M. (2014). Gerenciamento integrado de controles de projetos: Primeiro vem a teoria, e então a prática. *Mundo Project Management*, 59:52–56

URL

www.mundopm.com.br

Classification

Professional magazine; Written for professionals



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Controles de projetos

Neste artigo, farei uma abordagem curta, mas completa, dos temas discutidos no meu terceiro e mais recente livro sobre Project Management (PM), também destacarei as principais razões pelas quais eu escrevi este livro. O artigo mostra que o que me levou a escrever o terceiro livro é o fato de meus dois livros anteriores, intitulados *Medindo o tempo* e *cronogramas dinâmicos*, ainda parecerem ser uma necessidade aos estudantes e profissionais para obterem informações mais detalhadas sobre a área de gerenciamento de projetos. O artigo vai lhe dar uma visão da essência do livro e sua contribuição para a literatura nessa área. Além disso, vou fazer referências a meus estudos anteriores que foram usados como base para escrever este livro.

*Scientific advancement should
aim to affirm and to improve
human life.*
Nathan Deal



Project Management using dynamic scheduling: Baseline scheduling, risk analysis and project control

Vanhoucke, Mario

Tags

dynamic scheduling; earned schedule; earned value management; project control; project management; project scheduling; schedule risk analysis

Reference

Vanhoucke, M. (2013). Project Management using Dynamic Scheduling: Baseline scheduling, risk analysis and project control. *The Measurable News*, 2:45–50

URL

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Professional magazine; Written for professionals



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Book review

The purpose of this article is to give the reader a short yet complete overview of my new Project Management book that has recently been published by Springer. The general topic of this book is known as dynamic project scheduling and claims that project scheduling is a dynamic process that involves a continuous stream of changes and is a never ending process to support decisions that need to be made along the life of the project. Therefore, dynamic scheduling puts project control using Earned Value Management and project performance in a central place. More precisely, it focuses on the crucial role of the baseline schedule in order to assure a perfect integration with schedule risk analyses and an efficient project control approach. It is conjectured that this integration is key to support a better corrective action decision making when the project is in trouble.

If you are not willing to risk the unusual, you will have to settle for the ordinary.
Jim Rohn



Measuring schedule adherence

Vanhoucke, Mario

Tags

earned schedule; earned value management; project control; project management; schedule adherence

Reference

Vanhoucke, M. (2013). Measuring schedule adherence. *The Measurable News*, 4:21–26

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Schedule adherence

Ten years after the introduction of the Earned Schedule concept proposed by Lipke (2003), researchers and practitioners have investigated, validated, criticized and modified this novel concept and successfully used it in research simulation studies, software development and practical project control settings. Only one year later, Lipke (2004) proposed an extension on his Earned Schedule concept to measure the influence of rework due to the lack of scheduling adherence on the earned value. His new concept, known as the p-factor approach, measures the portion of the Earned Value (EV) accrued in congruence with the baseline schedule, which will be used to adapt the current EV to a so-called effective EV (EV(e)) taking the risk of rework into account. Unlike the ES concept, the p-factor approach has up to now stayed in the background, and little adoption by both researchers and practitioners has been detected. The aim of this article is to review this interesting p-factor concept with an artificial project example and to partially illustrate its strengths and weaknesses based on a research study using fictitious and empirical project data.

We're entering a new world in which data may be more important than software.
Tim O'Reilly



Dynamic scheduling: Integrating schedule risk analysis with earned value management

Vanhoucke, Mario

Tags

dynamic scheduling; earned schedule; earned value management; project control; project management; schedule risk analysis

Reference

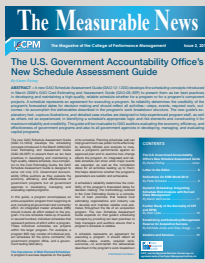
Vanhoucke, M. (2012). Dynamic Scheduling: Integrating Schedule Risk Analysis with Earned Value Management. *The Measurable News*, 2:11–13

URL

www.mycpm.org

Classification

Professional magazine; Written for professionals



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Risk & earned value

The topic of this paper is dynamic project scheduling to illustrate that project scheduling is a dynamic process that involves a continuous stream of changes and is a never ending process to support decisions that need to be made along the life of the project. The focus of this paper lies on three crucial dimensions of dynamic scheduling which can be briefly outlined along the following lines: (i) Baseline scheduling to construct a timetable that provides a start and end date for each project activity, taking activity relations, resource constraints and other project characteristics into account, and aiming to reach a certain scheduling objective, (ii) risk analysis to analyze the strengths and weaknesses of your project schedule in order to obtain information about the schedule sensitivity and the possible changes that undoubtedly occur during project progress and (iii) project control to 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 focus of the current paper is on the importance and crucial role of the baseline scheduling component for the two other components, and the integration of the schedule risk and project control component in order to support a better corrective action decision making when the project is in trouble.

The biggest risk is not taking any risk. In a world that changing really quickly, the only strategy that is guaranteed to fail is not taking risks.
Mark Zuckerberg



Adding value to earned value analysis

Vanhoucke, Mario; Shtub, Avraham

Tags

blended learning; business game; earned value management; project control; project management

Reference

Vanhoucke, M. and Shtub, A. (2011). Adding value to earned value analysis. *PM World Today*, XIII:Issue 1

URL

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Classification

Professional magazine; Written for professionals



Adding value

The non-repetitive nature of projects leads to uncertainty that is present to some degree in every project. Our limited ability to accurately forecast future values of parameters that are used as input to plan projects affect every project. Due to uncertainty and the resulting risk, project planning is in fact a starting point in the project management process that consists of planning, monitoring and control. Risk management techniques are also used in project management for the very same reason. Understanding the dynamic, stochastic nature of projects and the tools and techniques that can help us cope with this environment is the focus of this paper. In this paper we discuss some ideas, tools and techniques that may help project managers cope with uncertainty. We focus our discussion on two new ways to teach students and practitioners the Earned Value concept, which is discussed in the PMBOK and is supported by many of the commercial project management software packages: the Project Team Builder (PTB) and ProTrack's Assistant. PTB is a training tool that won the PMI product of the year award for 2008. ProTrack's Assistant is an automatic tool added on the ProTrack software tool that integrates lessons learned from an Earned Value research study awarded by the IPMA research 2008 award.

For changes to be of any true value, they've got to be lasting and consistent.
Tony Robbins



Measuring time: An earned value performance management study

Vanhoucke, Mario

Tags

dynamic scheduling; earned schedule; earned value management; forecasting; project control; project management; project scheduling; schedule risk analysis; simulation

Reference

Vanhoucke, M. (2010). Measuring time: An earned value performance management study. *The Measurable News*, 1:10–14

URL

www.mycpm.org

Classification

Professional magazine; Written for professionals



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Performance management

In this paper, I briefly describe the various topics of a new book that I have written as a summary of a large research study performed during the past 5 years. The research described in the book deals with the project performance and control phase of the project life cycle, and the corresponding feedback loop from control to planning and scheduling to take corrective actions when necessary (this is known as project tracking or project monitoring). More precisely, the focus is on a reactive scheduling early warning system by means of Earned Value Management (EVM) and Schedule Risk Analysis (SRA). For an overview of EVM, see e.g. Anbari (2003) or Fleming and Koppelman (2005). For an introduction to SRA, see Hulett (1996). Although EVM has been set up to follow up both time and cost, the majority of the research has been focused on the cost aspect. In the book, I focus on the time dimension which has received relatively less attention in the last decennia. The aim of the research is to measure the project performance sensitivity and the forecast accuracy (both in terms of time and cost, but with a focus on the time dimension) of the existing and newly developed metrics based on the principles of EVM and SRA. The research question boils down to the determination of when and in which cases SRA and EVM could lead to improved project tracking and corrective actions decision making.

*If you spend too much time
thinking about a thing, you'll
never get it done.*
Bruce Lee



Forecasting a project's duration under various topological structures

Vanhoucke, Mario; Vandevoorde, Stephan

Tags

earned schedule; earned value management; network analysis; project control; project management

Reference

Vanhoucke, M. and Vandevoorde, S. (2009). Forecasting a project's duration under various topological structures. *The Measurable News*, Spring:26–30

URL

www.mycpm.org

Classification

Professional magazine; Written for professionals



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Topological structure

In this third paper about the simulation study to measure the accuracy of three earned value based forecasting techniques to predict the final project duration, we elaborate on the influence of the degree of project criticality on the quality of project duration predictions. Based on simulation results of Vanhoucke and Vandevoorde (2007) and the network paper of Vanhoucke et al. (2008) we present an indicator to measure the structure of a project network, defined by the distribution of activities and the amount of precedence relations, and show that this measure clearly influences the accuracy of duration forecasting. Rather than drawing results on a small set of real-life projects, we present simulation results for a large and diverse set of different project networks in order to be able to draw general results that hold for a wide variety of projects in practice.

*The key to making a good forecast
is not in limiting yourself to
quantitative information.*
Nate Silver



Earned value forecast accuracy and activity criticality

Vanhoucke, Mario; Vandevoorde, Stephan

Tags

earned schedule; earned value management; project management; schedule risk analysis

Reference

Vanhoucke, M. and Vandevoorde, S. (2008). Earned value forecast accuracy and activity criticality. *The Measurable News*, Summer:13–16

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www.mycpm.org

Classification

Professional magazine; Written for professionals



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Accuracy & criticality

This paper presents new simulation results on the forecast accuracy of earned value based metrics to predict a project's final duration. This is the second paper in a series of papers based on the simulation study initially proposed by Vanhoucke and Vandevoorde (2007). In a previous manuscript published in the Measurable News (Vanhoucke and Vandevoorde, 2007), it has been shown that the earned schedule method outperforms, on average, the more traditional earned value based methods to predict the final duration of a project, both for early and late projects. In the current manuscript, the simulation study is extended to new simulation scenarios that measure the influence of inaccuracies in the planned duration estimates for critical and non-critical activities on the accuracy of forecasting methods.

Weather forecast for tonight: dark.
George Carlin



Measuring the accuracy of earned value/earned schedule forecasting predictors

Vanhoucke, Mario; Vandevoorde, Stephan

Tags

earned schedule; earned value management; forecasting; project management

Reference

Vanhoucke, M. and Vandevoorde, S. (2007). Measuring the accuracy of earned value/earned schedule forecasting predictors. *The Measurable News*, Winter:26–30

URL

www.mycpm.org

Classification

Professional magazine; Written for professionals



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Forecast accuracy

Earned value systems have been setup to deal with the complex task of controlling and adjusting the baseline project schedule during execution, taking into account project scope, timed delivery and total project budget. Although earned value systems have been proven to provide reliable estimates for the follow-up of cost performance within certain project assumptions, it often fails to predict the total duration of the project. In the current paper, a brief overview and summary is given of a simulation study that investigates the potential of three earned value based methods to forecast the final project duration. The study assumes a project setting where project activities and precedence relations are known in advance and do not consider fundamentally unforeseeable events and/or unknown interactions among various actions that might cause entirely unexpected effects in different project parts. This is the first paper in a sequence of papers that summarizes the results of the large simulation study initiated by the study of Vanhoucke and Vandevoorde (2007). Each paper will discuss and highlight another aspect of the simulation study.

*You can do the best research and
be making the strongest
intellectual argument, but if
readers don't get past the third
paragraph you've wasted your
energy and valuable ink.*
Carl Hiaasen



Part III

Book chapters

The multi-mode resource-constrained project scheduling problem

Coelho, José; Vanhoucke, Mario

Tags

boolean satisfiability problem; genetic algorithm; meta-heuristic; multi-mode; project management; resource constrained project scheduling

Reference

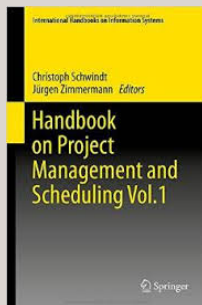
Coelho, J. and Vanhoucke, M. (2015). The resource-constrained multi-mode project scheduling problem. In Schwindt, C. and Zimmermann, J., editors, *Handbook on Project Management and Scheduling*, pages 491–511. Springer International Publishing AG

URL

www.springer.com

Classification

book chapter; Written for researchers



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Logic & scheduling

This chapter reports on a new solution approach for the multi-mode resource-constrained project scheduling problem (MRCPSP). This problem type aims at the selection of a single activity mode from a set of available modes in order to construct a precedence and a (renewable and nonrenewable) resource-feasible project schedule with a minimal makespan. The problem type is known to be NP-hard and has been solved using various exact as well as (meta-)heuristic procedures. The new algorithm splits the problem type into a mode assignment and a single mode project scheduling step. The mode assignment step is solved by a satisfiability (SAT) problem solver and returns a feasible mode selection to the project scheduling step. The project scheduling step is solved using an efficient meta-heuristic procedure from literature to solve the resource-constrained project scheduling problem (RCPSP). However, unlike many traditional meta-heuristic methods in literature to solve the MRCPSP, the new approach executes these two steps in one run, relying on a single priority list. Straightforward adaptations to the pure SAT solver by using pseudo boolean nonrenewable resource constraints has led to a high quality solution approach in a reasonable computational time. Computational results show that the procedure can report similar or sometimes even better solutions than found by other procedures in literature, although it often requires a higher CPU time.

If you don't work on important problems, it's not likely that you'll do important work.
Richard Hamming



Heuristic methods for the resource availability cost problem

Van Peteghem, Vincent; Vanhoucke, Mario

Tags

artificial immune system; meta-heuristic; project management; project scheduling; resource availability cost problem

Reference

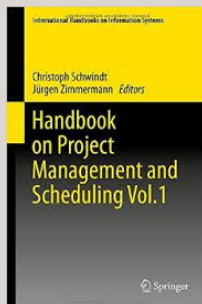
Van Peteghem, V. and Vanhoucke, M. (2015). Heuristic methods for the resource availability cost problem. In Schwindt, C. and Zimmermann, J., editors, *Handbook on Project Management and Scheduling*, pages 339–359. Springer International Publishing AG

URL

www.springer.com

Classification

book chapter; Written for researchers



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Heuristics cost optimization

In this chapter, an Invasive Weed Optimization (IWO) algorithm for the resource availability cost problem is presented, in which the total cost of the (unlimited) renewable resources required to complete the project by a prespecified project deadline should be minimized. The IWO algorithm is a new search strategy, which makes use of mechanisms inspired by the natural behavior of weeds in colonizing and finding a suitable place for growth and reproduction. All algorithmic components are explained in detail and computational results for the RACP are presented. The procedure is also executed to solve the RACP with tardiness (RACPT), in which lateness of the project is permitted with a predefined penalty.

Price is what you pay. Value is what you get.
Warren Buffett



Generalized discrete time-cost tradeoff problems

Vanhoucke, Mario

Tags

electromagnetism; meta-heuristic; project management; project scheduling; time/cost trade-off problem

Reference

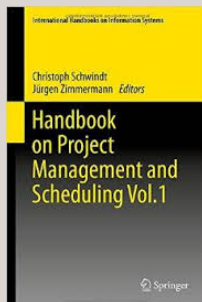
Vanhoucke, M. (2014). Generalized discrete time-cost tradeoff problems. In Schwindt, C. and Zimmermann, J., editors, *Handbook on Project Management and Scheduling*, pages 639–658. Springer International Publishing AG

URL

www.springer.com

Classification

book chapter; Written for researchers



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Generalized trade-offs

Time-cost tradeoffs have been extensively studied in the literature since the development of the critical path method. Recently, the discrete version of the problem formulation has been extended to various practical assumptions, and solved with both exact and heuristic optimisation procedures, as described in Vanhoucke and Debels (J Sched 10:311-326, 2007). In this chapter, an overview is given of four variants of the discrete time-cost tradeoff problem and a newly developed electromagnetic meta-heuristic (EM) algorithm to solve these problems is presented. We extend the standard electromagnetic meta-heuristic with problem specific features and investigate the influence of various EM parameters on the solution quality. We test the new meta-heuristic on a benchmark set from the literature and present extensive computational results.

A good decision is based on knowledge and not on numbers.
Plato



Managing cost and earned value

Vanhoucke, Mario

Tags

earned schedule; earned value management; project management

Reference

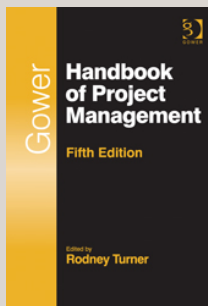
Vanhoucke, M. (2014). Managing cost and earned value. In Turner, R., editor, *Gower Handbook of Project Management*, pages 247–261. Gower Publishing

URL

www.ashgate.com

Classification

book chapter; Written for students and professionals



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Managing cost

In this chapter we look at the management of costs on projects, and in particular at the use of the Earned Value Management system. Earned Value Management (EVM) is a methodology used to measure and communicate the real physical progress of a project and to integrate the three critical elements of project management (scope, time and cost management). It takes into account the work completed, the time taken and the costs incurred to complete the project and it helps to evaluate and control project risks by measuring project progress in monetary terms. The basic principles and the use in practice have been comprehensively described in many sources (for an overview, see Fleming and Koppelman (2005)). Although EVM has been set up to follow up both time and cost, the majority of the research endeavors and practical applications have been focused on the cost aspect. It is only recently that the time dimension has received attention from both practitioners and academics. This chapter reviews the basic key metrics used in earned value management, describes their usefulness for measuring both a project's time and cost performance and highlights the importance of integrating EVM with risk management.

The first rule of management is delegation. Don't try and do everything yourself because you can't.

Anthea Turner



The impact of project schedule adherence and rework on the duration forecast accuracy of earned value metrics

Vanhoucke, Mario

Tags

earned schedule; earned value management; project management; schedule adherence

Reference

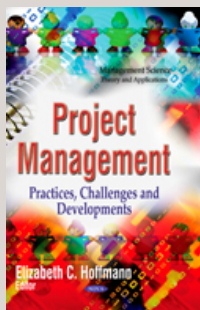
Vanhoucke, M. (2013). The impact of project schedule adherence and rework on the duration forecast accuracy of earned value metrics. In Hoffmann, E. C., editor, *Project Management: Practices, Challenges and Developments*. NOVA Publishers

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www.novapublishers.com

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book chapter; Written for researchers and professionals



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Adherence & rework

Earned Value Management (EVM) in project management integrates cost, schedule and technical performance and allows the calculation of cost and schedule variances, performance indices and forecasts of project cost and schedule duration. The earned value method provides early indicators of project performance to reveal opportunities and/or highlight the need for eventual corrective actions. The introduction of the earned schedule (ES) method in 2003 has led to an increasing attention on the forecast accuracy of EVM to predict a project's final duration. Previous research has shown that the ES method outperforms the more traditional predictive metrics for project duration forecasting. In this paper we critically review and test a novel ES extension, the p-factor approach, to measure schedule adherence based on the traditional earned value metrics. A large set of fictitious project networks has been constructed under a controlled design and performance is measured by means of Monte Carlo simulations.

*For the things we have to learn
before we can do them, we learn
by doing them.*
Aristotle



An empirical investigation of different solution strategies for meta-heuristic optimization: Solution representation, diversity and space reduction

Vanhoucke, Mario; Maenhout, Broos

Tags

meta-heuristic; personnel scheduling; resource constrained project scheduling

Reference

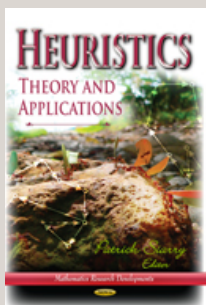
Vanhoucke, M. and Maenhout, B. (2013). An empirical investigation of different solution strategies for meta-heuristic optimization: Solution representation, diversity and space reduction. In Siarry, P., editor, *Heuristics: Theory and Applications*, pages 53–68. NOVA Publishers

URL

www.novapublishers.com

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book chapter; Written for researchers



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Solution strategies

In this chapter we study the characteristics of population based meta-heuristics that distinguish the procedures from a standard meta-heuristic and that positively contribute to the quality of the solutions obtained. More precisely, we investigate and discuss the importance of a well-considered solution representation, the beneficial effect of diversity in the solution population and the possible improving effect of solution space reduction techniques on the overall quality of the solution. Empirical results are obtained by a computational experiment of different meta-heuristics on resource-constrained project scheduling and personnel scheduling problems.

*If you've got an idea, start today.
There's no better time than now to
get going.*
Kevin Systrom



Genetic algorithms for single machine scheduling problems: a trade-off between intensifications and diversification

Sels, Veronique; Vanhoucke, Mario

Tags

genetic algorithm; meta-heuristic; production scheduling; single machine scheduling

Reference

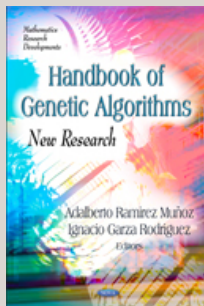
Sels, V. and Vanhoucke, M. (2012). Genetic algorithms for single machine scheduling problems: a trade-off between intensifications and diversification. In Muñoz, A. and Rodriguez, I., editors, *Handbook of Genetic Algorithms: New Research*, pages 265–293. NOVA Publishers

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Intensification & diversification

In order to increase the efficiency of genetic algorithms, these algorithms are often hybridized with other heuristic procedures, such as local search algorithms or other meta-heuristics. The main purpose of this hybridization is to intensify the search process of the genetic algorithm in order to accelerate the search for high quality solutions. However, diversity is also a crucial component of the genetic algorithm that will guarantee a uniform sample of the search space. Therefore, hybrid algorithms require a careful trade-off between the diversification and intensification strategy. In this chapter, we discuss several techniques that take this important balance into account. To be more precise, we will show that the definition of a clever, often restricted, neighborhood increases the effectiveness of the embedded local search algorithm or meta-heuristic. In addition, we will discuss how the extension from a single population to multiple populations and the use of a distance measure to define these populations can be an important stimulator to add diversity to the search process. These techniques are illustrated by means of a commonly known machine scheduling problem.

*Bad times have a scientific value.
These are occasions a good learner
would not miss.*
Ralph Waldo Emerson



Days on and days off scheduling of pilots under a variable workload

Maenhout, Broos; Vanhoucke, Mario

Tags

crew scheduling; personnel scheduling

Reference

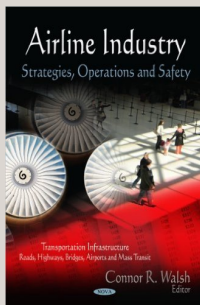
Maenhout, B. and Vanhoucke, M. (2011). Days on and days off scheduling of pilots under a variable workload. In Walsh, C., editor, *Airline industry: Strategies, Operations and Safety*, pages 193–212. NOVA Publishers

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book chapter; Written for researchers and professionals



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Crew scheduling

Personnel costs typically are the second largest costs for airline operations after fuel costs. Since efficient crew employment can drastically reduce operational costs of airline companies, the crew scheduling problem in the airline industry has been extensively investigated in the operations research literature. This problem typically consists of assigning duties to crew members securing the safety of all flights minimizing the corresponding overall cost for personnel. Due to the typical size and complexity of the crew rostering problem, airline companies want to adopt scheduling policies that roster crew members according to fixed days on and days off patterns. However, as the distribution of work duties over the planning horizon is typically highly variable in airline operations, the scheduling according to these fixed work patterns is seriously hindered. In this chapter, we give an overview of different measures that help to schedule airline crew under a variable workload using fixed days on and days off patterns.

Lost time is never found again.
Benjamin Franklin



Static and dynamic determinants of earned value based time forecast accuracy

Vanhoucke, Mario

Tags

earned value management;
forecasting; project management

Reference

Vanhoucke, M. (2009). Static and dynamic determinants of earned value based time forecast accuracy. In Kidd, T., editor, *Handbook of Research on Technology Project Management, Planning, and Operations*, pages 361–374. Information Science Reference

URL

www.igi-global.com

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book chapter; Written for researchers and professionals



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Accuracy determinants

It is well-known that well managed and controlled projects are more likely to be delivered on time and within budget. The construction of a (resource-feasible) baseline schedule and the follow-up during execution are primary contributors to the success or failure of a project. Earned value management systems have been set up to deal with the complex task of controlling and adjusting the baseline project schedule during execution. Although earned value systems have been proven to provide reliable estimates for the follow-up of cost performance, they often fail to predict the total duration of the project. In this chapter, results of a large simulation study to evaluate the forecast accuracy of earned value based predictive metrics are presented. No detailed mathematical calculations are presented in the chapter, but instead an overview from a project life cycle point-of-view is presented. Details can be found at the end of the chapter (key terms and their definitions) or in the references cited throughout this chapter.

*The most reliable way to forecast
the future is to try to understand
the present.*
John Naisbitt



Part IV

Books

Integrated project management sourcebook: A technical guide to project scheduling, risk and control

Vanhoucke, Mario

Tags

critical chain; dynamic scheduling; earned value management; priority rules; project control; project management; project scheduling; schedule adherence; schedule risk analysis

Reference

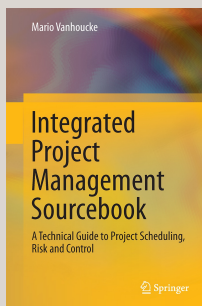
Vanhoucke, M. (2016). *Project management knowledge center: The technical guide for baseline scheduling, schedule risk analysis and project control*, volume In Press. Springer

URL

www.or-as.be/books

Classification

book; Written for students and researchers; Solutions available at www.or-as.be/books/pmkc



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PM Knowledge Center

This book is intended to be the Project Management Knowledge Sourcebook for students of any Project Management course focusing on the integration between baseline scheduling, schedule risk analysis and project control. This integration is known as "Dynamic Scheduling" or "Integrated Project Management and Control". The book is intended to be a technical guide that contains a set of +70 articles classified in the three main book themes, and each article contains links to other relevant articles of the book. The articles are accompanied with a set of questions to enable the reader to test his/her knowledge and understanding of the article's theme, for which the answers are provided at the end of this book.

Knowledge is of two kinds. We know a subject ourselves, or we know where we can find information upon it.
Samuel Johnson



The art of project management: A story about work and passion

Vanhoucke, Mario

Tags

baseline scheduling; blended learning; business game; dynamic scheduling; project control; project management; schedule risk analysis

Reference

Vanhoucke, M. (2015). *The Art of Project Management: A Story about Work and Passion*. Available online at www.or-as.be (third edition)

URL

www.or-as.be/books

Classification

book; Written for students and professionals



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Work & passion

The book contains stories about friendship, ideas, hard work and results on Project Management. It gives you a look into the endeavors done in the past and the ideas that will be done in the future. It tells about the products and ideas of OR-AS and gives you a brief overview of the most important people who inspired us and the OR-AS products. It tells about work, and the passion that has led to the results of the hard work. It's not a scientific book. It isn't a managerial book either. It's just a story ... about work and passion.

If you only read the books that everyone else is reading, you can only think what everyone else is thinking.
Haruki Murakami



Taking sound business decisions: From rich data to better solutions

Vanhoucke, Mario

Tags

decision tree analysis; linear programming; integer programming; simulation

Reference

Vanhoucke, M. (2015). *Taking sound business decisions: From rich data to better solutions*. Available online at www.or-as.be

URL

www.or-as.be/books

Classification

book; Written for students and professionals; Examples available at www.or-as.be/books/tsbd



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Decision making

The book gives an introduction to the world of mathematical programming and data analytics and is mainly written for M.Sc. and MBA students at Ghent University, Vlerick Business School and UCL School of Management of University College London. On top of that, the book also contains an overview of research studies and company applications of data-driven modelling technique developed by the Operations Research & Scheduling group, which makes the book potentially relevant for researchers and professionals interested in the new data-driven management approach. The book is free for download via the OR-AS site and will be updated on a regular basis upon requests and comments of the readers.

Whenever you see a successful business, someone once made a courageous decision.
Peter Drucker



Integrated project management and control: First comes the theory, then the practice

Vanhoucke, Mario

Tags

earned schedule; earned value management; project control; project management; schedule risk analysis

Reference

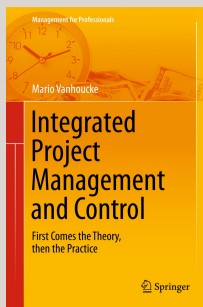
Vanhoucke, M. (2014). *Integrated Project Management and Control: First comes the theory, then the practice*. Management for Professionals. Springer

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www.or-as.be/books

Classification

book; Written for students, researchers and professionals

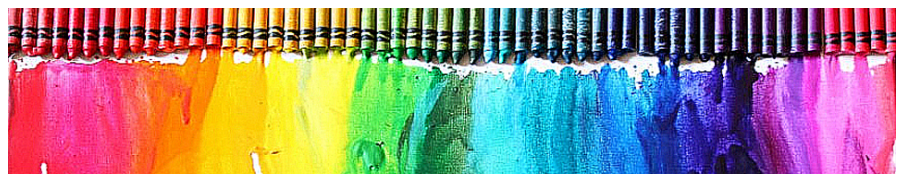


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Integrated project control

This book presents an integrated approach to monitoring projects in progress using Earned Value and Earned Schedule Management combined with Schedule Risk Analysis. Monitoring and controlling projects involves processes for identifying potential problems in a timely manner. When necessary, corrective actions can be taken to exploit project opportunities or to get faltering projects back on track. The prerequisite is that project performance is observed and measured regularly to identify variances from the project baseline schedule. Therefore, monitoring the performance of projects in progress requires a set of tools and techniques that should ideally be combined into a single integrated system. The book offers a valuable resource for anyone who wants to understand the theory first and then to use it in practice with software tools.

*Either write something worth
reading or do something worth
writing.*
Benjamin Franklin



Project management with dynamic scheduling: Baseline scheduling, risk analysis and project control

Vanhoucke, Mario

Tags

business game; critical chain/buffer management; dynamic scheduling; earned schedule; earned value management; project control; project management; resource constrained project scheduling; schedule risk analysis

Reference

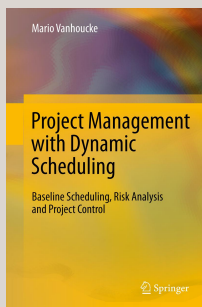
Vanhoucke, M. (2012). *Project Management with Dynamic Scheduling: Baseline Scheduling, Risk Analysis and Project Control*, volume XVIII. Springer

URL

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Classification

book; Written for students



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Dynamic scheduling

The topic of this book is known as dynamic scheduling, and is used to refer to three dimensions of project management and scheduling: the construction of a baseline schedule and the analysis of a project schedule's risk as preparation of the project control phase during project progress. First, the construction of a project baseline schedule is a central theme throughout the various chapters of the book, and is discussed from a complexity point of view with and without the presence of project resources. Second, the creation of an awareness of the weak parts in a baseline schedule is discussed at the end of the two baseline scheduling parts as schedule risk analysis techniques that can be applied on top of the baseline schedule. Third, the baseline schedule and its risk analyses can be used as guidelines during the project control step where actual deviations can be corrected within the margins of the project's time and cost reserves.

Life is inherently risky. There is only one big risk you should avoid at all costs, and that is the risk of doing nothing.
Denis Waitley



Measuring time: Improving project performance using earned value management

Vanhoucke, Mario

Tags

earned schedule; earned value management; project control; project management; schedule adherence; schedule risk analysis; simulation

Reference

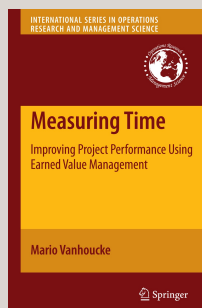
Vanhoucke, M. (2010). *Measuring Time - Improving Project Performance using Earned Value Management*, volume 136 of *International Series in Operations Research and Management Science*. Springer

URL

www.or-as.be/books

Classification

book; Written for researchers; Artificial project data available at www.projectmanagement.ugent.be



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Measuring time

Meant to complement rather than compete with the existing books on the subject, this book deals with the project performance and control phases of the project life cycle to present a detailed investigation of the project's time performance measurement methods and risk analysis techniques in order to evaluate existing and newly developed methods in terms of their abilities to improve the corrective actions decision-making process during project tracking. As readers apply what is learned from the book, EVM practices will become even more effective in project management and cost engineering. Individual chapters look at simulation studies in forecast accuracy, schedule adherence, time sensitivity, activity sensitivity and using top-down or bottom-up project tracking. The book also offers an actual real-life case study, a short tutorial on the EVM use in ProTrack, and conclusions on the relative effectiveness for each technique presented.

The only reason for time is so that everything doesn't happen at once.
Albert Einstein



Dynamic scheduling on your desktop

Vanhoucke, Mario

Tags

earned schedule; earned value management; project control; project management; project scheduling; schedule adherence; schedule risk analysis

Reference

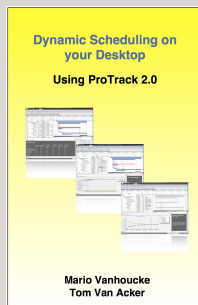
Vanhoucke, M. and Van Acker, T. (2010). *Dynamic Scheduling on your Desktop*. Available online at www.or-as.be/books

URL

www.or-as.be/books

Classification

book; Written for researchers and professionals; Software available at www.protrack.be



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PM software

The book contains information on baseline scheduling, risk analysis and project control using ProTrack 2.0. Although ProTrack has fundamentally changed ever since the release of the book, it is still used as background information on the dynamic scheduling theme. It is interesting to ProTrack users but also to newcomers interested in the integration between scheduling, risk analysis and project control.

*A mind needs books as a sword
needs a whetstone, if it is to keep
its edge.*

George R.R. Martin



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