

NURSE ROSTERING

Focus on models or algorithms?

Greet Vanden Berghe
KU Leuven
CHOIR in Practice, 22 November 2013



Taxonomy personnel rostering

A.T. Ernst et al. (2004), Staff scheduling and rostering: A review of applications, methods and models, *EJOR* 153:3-27

- Rostering
 - ▶ Demand modelling
 - ▶ Shift based demand
- Days off scheduling
- Shift scheduling
- Task assignment
- Staff assignment

J. Van den Bergh, J. Beliën, P. De Bruecker, E. Demeulemeester, L. De Boeck (2013), Personnel scheduling: A literature review

Definition

Nurse rostering

Distribute shifts over the qualified members of staff in order to meet the coverage requirements, taking into account legal and contractual constraints and personal preferences.



Home	Reference Collections
History	22nd of Jun, 2010
News	A List of Recent Papers in Nurse Rostering (Feb 2007) Online Resources Database - at the PLANET Network
Past events	Practice and Theory of Automated Timetabling - The Bibliography
Application Areas	WATT Bibliography updated up to 1996 and ordered by author
Educational timetabling	Comprehensive bibliography (in BibTeX) compiled by Jeffrey Kingston
Employee timetabling	
Sports timetabling	
WATT Digests	Benchmark Data Sets
Archive	Staff Rostering - Problem instances and solution verifier graphical user interface
WATT Membership	Employee Timetabling Problems - Problem generator and solver
Why join?	Nurse Rostering - Problem instances archive
How to join?	Nurse rostering at QMC, Nottingham
Current members	Shift scheduling problem - Sets of random examples
Contact Us	Nurse Rostering - Problem Instances Archive
	Related Resources
	Personnel Scheduling Research , at the University of Nottingham
	Contact:
	For further information, please contact Dr. Timothy Curtois (HTTP , e-mail)
	29th of November, 2010

Nurse rostering competition 2010

The screenshot shows the website for the Nurse Rostering Competition 2010. At the top, it says "NURSE ROSTERING COMPETITION" and "PATAT 2010". There are navigation links for Home, Important dates, Competition Rules, Benchmarking, and Winner. The main content area is titled "Welcome" and contains several paragraphs of text. On the right side, there is a section for "Organising Partners" featuring logos for CODeS and SINTEF, and a "Competition Chair" section listing prof. dr. Patrick De Causmaecker and the CODeS research group.

NURSE ROSTERING
COMPETITION

Log in Register

PATAT 2010

Home Important dates Competition Rules Benchmarking Winner

Solutions

Home

Welcome

The overall orderings and winners of each track will be announced at PATAT 2010. In a special session, competitors can present their results and techniques. Submissions for this session are allowed up until the end of July.

Building on the success of the two timetabling competitions, this competition on the nurse rostering problem aims to further develop interest in the general area of rostering and timetabling while providing researchers with models of the problems faced which incorporate an increased number of real world constraints.

Building good rosters for nurses in hospitals has received ample attention in recent years and is recognised as a difficult combinatorial optimisation problem with practical relevance. In hospitals much effort is spent producing solutions which are workable and of a high quality.

An important aim of this competition is to generate new approaches to the associated problems by attracting users from all areas of research. As with many cases in the past, significant advancements have been made in research areas by attracting multi-disciplinary approaches.

Organising Partners

CODeS

SINTEF

Scheduling & Timetabling Group
CODeS - University of Leuven

Competition Chair

prof. dr. Patrick De Causmaecker

CODeS research group
Etienne Sabbelaan 53
3500 Kortrijk
Belgium
E-mail

S. Haspeslagh et al. (to appear)
The first international nurse rostering competition 2010,
Annals of OR

Web of Knowledge

All Databases | **Select a Database** | Web of Science | Additional Resources

[Search](#) | [Search History](#) | Compound Marked List (0)

All Databases

[<< Back to previous page](#)

Citation Report

Topic=(personnel scheduling OR rostering)
Timespan=1955-2012.

This report reflects citations to source items indexed within All Databases.

Published Items in Each Year

Year	Published Items
1955	95
1956	100
1957	105
1958	110
1959	115
1960	120
1961	110
1962	115
1963	110
1964	115
1965	110
1966	115
1967	110
1968	115
1969	110
1970	115
1971	110
1972	115
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1994	115
1995	110
1996	115
1997	110
1998	115
1999	110
2000	115
2001	110
2002	115
2003	110
2004	115
2005	110
2006	115
2007	110
2008	115
2009	110
2010	115
2011	110
2012	115

The latest 20 years are displayed.
[View a graph with all years.](#)

Citations in Each Year

Year	Citations
1955	10
1956	15
1957	20
1958	25
1959	30
1960	35
1961	40
1962	45
1963	50
1964	55
1965	60
1966	65
1967	70
1968	75
1969	80
1970	85
1971	90
1972	95
1973	100
1974	105
1975	110
1976	115
1977	120
1978	125
1979	130
1980	135
1981	140
1982	145
1983	150
1984	155
1985	160
1986	165
1987	170
1988	175
1989	180
1990	185
1991	190
1992	195
1993	200
1994	205
1995	210
1996	215
1997	220
1998	225
1999	230
2000	235
2001	240
2002	245
2003	250
2004	255
2005	260
2006	265
2007	270
2008	275
2009	280
2010	285
2011	290
2012	295

The latest 20 years are displayed.
[View a graph with all years.](#)

Results found: 3124

Sum of the Times Cited [?]: 17556

Sum of Times Cited without self-citations [?]: 14566

Citing Articles [?]: 12557

Citing Articles without self-citations [?]: 12041

Average Citations per Item [?]: 5.62

h-Index [?]: 56

Results: 3,124

Page 1 of 313 Go

Sort by: Times Cited – highest to lowest

10 most cited papers

1. Title: **Physician staffing patterns and clinical outcomes in critically ill patients - A systematic review**
Author(s): Pronovost, PJ; Angus, DC; Dorman, T; et al.
Conference: **Society-of-Critical-Care-Medicine-Educational-and-Scientific Symposium** Location: **ORLANDO, FLORIDA** Date: **FEB 12-16, 2000**
Sponsor(s): **Soc Crit Care Med**
Source: JAMA-JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION Volume: **288** Issue: **17** Pages: **2151-2162** DOI: **10.1001/jama.288.17.2151** Published: **NOV 6 2002**
2. Title: **SOLVING AIRLINE CREW SCHEDULING PROBLEMS BY BRANCH-AND-CUT**
Author(s): HOFFMAN, KL; PADBERG, M
Source: MANAGEMENT SCIENCE Volume: **39** Issue: **6** Pages: **657-682** DOI: **10.1287/mnsc.39.6.657** Published: **JUN 1993**
3. Title: **Staff scheduling and rostering: A review of applications, methods and models**
Author(s): Ernst, AT; Jiang, H; Krishnamoorthy, M; et al.
Source: EUROPEAN JOURNAL OF OPERATIONAL RESEARCH Volume: **153** Issue: **1** Pages: **3-27** DOI: **10.1016/S0377-2217(03)00095-X** Published: **FEB 16 2004**
4. Title: **Virtually perfect time sharing in dual-task performance: Uncorking the central cognitive bottleneck**
Author(s): Schumacher, EH; Seymour, TL; Glass, JM; et al.
Source: PSYCHOLOGICAL SCIENCE Volume: **12** Issue: **2** Pages: **101-108** DOI: **10.1111/1467-9280.00318** Published: **MAR 2001**
5. Title: **A tabu-search hyperheuristic for timetabling and rostering**
Author(s): Burke, EK; Kendall, G; Soubeiga, E
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6. Title: **The state of the art of nurse rostering**
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7. Title: **ANALYSIS OF STRATEGIES TO DECREASE POSTANESTHESIA CARE UNIT COSTS**
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Source: ANESTHESIOLOGY Volume: **82** Issue: **1** Pages: **94-101** DOI: **10.1097/00000542-199501000-00013** Published: **JAN 1995**
8. Title: **SCHEDULING NURSING PERSONNEL ACCORDING TO NURSING PREFERENCE - MATHEMATICAL-PROGRAMMING APPROACH**
Author(s): WARNER, DM
Source: OPERATIONS RESEARCH Volume: **24** Issue: **5** Pages: **842-856** DOI: **10.1287/oprre.24.5.842** Published: **1976**
9. Title: **UNDERSTANDING AND CONTROLLING SOFTWARE COSTS**
Author(s): BOEHM, BW; PAPPACIO, PN
Source: IEEE TRANSACTIONS ON SOFTWARE ENGINEERING Volume: **14** Issue: **10** Pages: **1462-1477** DOI: **10.1109/32.6191** Published: **OCT 1988**
10. Title: **Emergency logistics planning in natural disasters**
Author(s): Ozdamar, L; Ekinci, E; Kucukyazici, B
Conference: **Biennial Workshop on Models and Algorithms for Planning and Scheduling Problems (MAPSP)** Location: **Aussels, FRANCE** Date: **JUN 17-22, 2001**
Source: ANNALS OF OPERATIONS RESEARCH Volume: **129** Issue: **1-4** Pages: **217-245** DOI: **10.1023/B:ANOR.0000030690.27939.39** Published: **JUL 2004**

Health care

- 1. Title: **Physician staffing patterns and clinical outcomes in critically ill patients - A systematic review**
Author(s): **Preussner, P.J., Angus, D.C., Dorman, T.** et al.
Conference: **Society-of-Critical-Care-Medicine-Educational-and-Scientific Symposium** Location: **ORLANDO, FLORIDA** Date: **FEB 12-16, 2000**
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Author(s): **DEXTER, F, TINKER, JL**
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Logistics

- 1. Title: **Physician staffing patterns and clinical outcomes in critically ill patients - A systematic review**
Author(s): Pronovost, P.J; Angus, D.C; Dorman, T, et al.
Conference: **Society of Critical-Care-Medicine-Educational-and-Scientific Symposium** Location: **ORLANDO, FLORIDA** Date: **FEB 12-16, 2000**
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Surveys

1. Title: **Physician staffing patterns and clinical outcomes in critically ill patients - A systematic review**
Author(s): Pronovost, P.J.; Angus, D.C.; Dorman, T.; et al.
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Algorithms

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Source: [EUROPEAN JOURNAL OF OPERATIONAL RESEARCH](#) Volume: [153](#) Issue: [1](#) Pages: [3-27](#) DOI: [10.1016/S0377-2217\(03\)00095-X](#) Published: [FEB 16 2004](#)
4. Title: [Virtually perfect time sharing in dual-task performance: Uncorking the central cognitive bottleneck](#)
Author(s): Shenmaacher, EY; Seymour, TL; Glass, JM; et al.
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5. Title: [A tabu-search hyperheuristic for timetabling and rostering](#)
Author(s): Burke, EK; Kendall, G; Soubeiga, E
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6. Title: [The state of the art of nurse rostering](#)
Author(s): Burke, EK; De Causmaecker, P; Vanden Berghe, G; et al.
Source: [JOURNAL OF SCHEDULING](#) Volume: [7](#) Issue: [6](#) Pages: [441-499](#) DOI: [10.1023/B:JOSH.0000046076.75950.0b](#) Published: [NOV-DEC 2004](#)
7. Title: [ANALYSIS OF STRATEGIES TO DECREASE POSTANESTHESIA CARE UNIT COSTS](#)
Author(s): DEXTER, F; TINKER, JH
Source: [ANESTHESIOLOGY](#) Volume: [82](#) Issue: [1](#) Pages: [94-101](#) DOI: [10.1097/0000542-199501000-00013](#) Published: [JAN 1995](#)
8. Title: [SCHEDULING NURSING PERSONNEL ACCORDING TO NURSING PREFERENCE - MATHEMATICAL-PROGRAMMING APPROACH](#)
Author(s): WARNER, DM
Source: [OPERATIONS RESEARCH](#) Volume: [24](#) Issue: [3](#) Pages: [842-856](#) DOI: [10.1287/opre.24.5.842](#) Published: [1976](#)
9. Title: [UNDERSTANDING AND CONTROLLING SOFTWARE COSTS](#)
Author(s): BOEHM, BW; PAPACCIO, PN
Source: [IEEE TRANSACTIONS ON SOFTWARE ENGINEERING](#) Volume: [14](#) Issue: [10](#) Pages: [1462-1477](#) DOI: [10.1109/32.6191](#) Published: [OCT 1988](#)
10. Title: [Emergency logistics planning in natural disasters](#)
Author(s): Ozdamar, L; Ekinci, E; Kucukyazici, B
Conference: [Biennial Workshop on Models and Algorithms for Planning and Scheduling Problems \(MAPSP\)](#) Location: [Aussais, FRANCE](#) Date: [JUN 17-22, 2001](#)
Source: [ANNALS OF OPERATIONS RESEARCH](#) Volume: [129](#) Issue: [1-4](#) Pages: [217-245](#) DOI: [10.1023/B:ANOR.0000030690.27939.39](#) Published: [JUL 2004](#)

Software

- 1. Title: **Physician staffing patterns and clinical outcomes in critically ill patients - A systematic review**
Author(s): Pronovost, PJ; Angus, DC; Dorman, T; et al.
Conference: **Society-of-Critical-Care-Medicine-Educational-and-Scientific Symposium** Location: **ORLANDO, FLORIDA** Date: **FEB 12-16, 2000**
Sponsor(s): **Soc Crit Care Med**
Source: JAMA-JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION Volume: **288** Issue: **17** Pages: **2151-2162** DOI: **10.1001/jama.288.17.2151** Published: **NOV 6 2002**
- 2. Title: **SOLVING AIRLINE CREW SCHEDULING PROBLEMS BY BRANCH-AND-CUT**
Author(s): HOFFMAN, KL; PADBERG, M
Source: MANAGEMENT SCIENCE Volume: **39** Issue: **6** Pages: **657-682** DOI: **10.1287/mnsc.39.6.657** Published: **JUN 1993**
- 3. Title: **Staff scheduling and rostering: A review of applications, methods and models**
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Where is the theory?

Fifty Years of Vehicle Routing

Gilbert Laporte

CIRRELT, Distribution Management, HEC Montréal, 3000, Montréal, Québec H3T 2A7, Canada
gilbert@crt.umontreal.ca

The *Vehicle Routing Problem* (VRP) was introduced 50 years ago by Dantzig and Ramser under the title “The Truck Dispatching Problem.” The study of the VRP has given rise to major developments in the fields of exact algorithms and heuristics. In particular, highly sophisticated exact mathematical programming decomposition algorithms and powerful metaheuristics for the VRP have been put forward in recent years. The purpose of this article is to provide a brief account of this development.

Key words: vehicle routing problem; traveling salesman problem; exact algorithms; heuristics; metaheuristics; survey

History: Received: August 2009; revision received: September 2009; accepted: September 2009. Published online in *Articles in Advance* October 21, 2009.

Scheduling

Peter Brucker, University of Osnabruck: 29 pages theory

- Single machine problems
- Parallel machine problems without preemption
- ...
- Serial batching problems
- ...
- Flow shop problems with transportation times and a single robot
- ...
- Flow shop problems with a single server

Scheduling

last update: 03.07.06 (SK) <http://www.mathematik.uni-osnabrueck.de/research/OR/class>

Single machine problems

• maximal polynomially solvable:

$1 prec; r_i C_{max}$	Lawler (1973)
$1 prec; p_i = p; r_i L_{max}$	Simons (1978)
$1 prec; r_i; pmtn L_{max}$	Blazewicz (1976), Baker et al. (1983)
$1 prec; p_i = p; r_i \sum C_i$	Simons (1983)
$1 prec; pmtn; p_i = p; r_i \sum C_i$	Baptiste et al. (2004)
$1 r_i; pmtn \sum C_i$	Baker (1974)
$1 p_i = p; r_i \sum w_i C_i$	Baptiste (2000)
$1 sp - graph \sum w_i C_i$	Lawler (1978)
$1 r_i; pmtn \sum U_i$	Lawler (1990)
$1 p_i = p; r_i \sum w_i U_i$	Baptiste (1999)
$1 pmtn; p_i = p; r_i \sum w_i U_i$	Baptiste (1999)
$1 p_i = p; r_i \sum T_i$	Baptiste (2000)
$1 pmtn; p_i = p; r_i \sum T_i$	Tian et al. (2006)
$1 p_i = 1; r_i \sum w_i T_i$	Assignment-problem

• maximal pseudopolynomially solvable:

$1 r_i; pmtn \sum w_i U_i$	Lawler (1990)
$1 \sum T_i$	Lawler (1977), Du & Leung (1990)

• minimal NP-hard:

* $1 r_i L_{max}$	Lenstra et al. (1977)
* $1 chains; r_i; pmtn \sum C_i$	Lenstra (-)
* $1 prec \sum C_i$	Lawler (1978), Lenstra & Rinnooy Kan (1978)
* $1 r_i \sum C_i$	Lenstra et al. (1977)
* $1 chains; p_i = 1; r_i \sum w_i C_i$	Lenstra & Rinnooy Kan (1980)
* $1 prec; p_i = 1 \sum w_i C_i$	Lawler (1978), Lenstra & Rinnooy Kan (1978)
* $1 r_i; pmtn \sum w_i C_i$	Labetoulle et al. (1984)

Where is the theory?

NP-hard problem

- H.C. Lau (1996) On the complexity of manpower shift scheduling, *Computers & OR*, 23(1): 93-102
- T. Osogami, H. Imai (2000) Classification of various neighbourhood operations for the nurse scheduling problem, *Lecture Notes in Computer Science*, 1969: 72-83
- M. Moz and M. Vaz Pato (2007) A genetic algorithm approach to a nurse rostering problem (!reference to a Portugese proof), *Computers & OR*, 34: 667-691

- P. Brucker, R. Qu, E.K. Burke (2011) Personnel scheduling: Models and complexity, *EJOR* 210 (3): 467-473
- M. Rocha, J.F. Oliveira, M.A. Carravilla (2013) Cyclic staff scheduling: optimization models for some real-life problems *Journal of Scheduling*, 16 (2): 231-242

Categorisation nurse rostering

α Personnel environment	Personnel constraints		Skill interactions	
	A	Availability	2,3,...	Fixed number
	S	Sequences	N	Variable number
	B	Balance	I	Individual skill definitions
	C	Chaperoning		
β Work characteristics	Coverage constraints		Shift type	
	R	Range	2,3,...	Fixed number
	T	Time Intervals	N	Variable number
	V	Fluctuating	O	Overlapping
γ Optimisation objective	Objective		Mode	
	P	Personnel constraints	M	Multi objective
	L	Coverage constraints		
	X	Number of personnel		
	R	Robustness		
	G	General		

P. De Causmaecker, G. Vanden Berghe (2011) *A categorisation of nurse rostering problems*, Journal of Scheduling, 14(1): 3-16

Where is the rest of the theory?

Personnel scheduling

Can personnel scheduling reach the same **academic status** as vehicle routing, scheduling?

What do we need?

Effort to establish theory

$AI|RVN|G$

formulated as integer minimum cost flow problems: **polynomially solvable**

Pieter Smet, Peter Brucker, Patrick De Causmaecker, Greet Vanden Berghe (2013)

Where are the applications?

Model	Implementation-knowledge source	Still in use	Model type*	Location	Implementation site and number	Product name if commercialized
Azaiez	Article	Unknown	MP	Saudi Arabia	1 hospital	
Bellanti	Article	Unknown	H	Italy	1 ward/unit	
Liao	Article	Unknown	H	Taiwan	1 hospital	
Weil	Article	Unknown	H	France	Commercial product	Gymnaste
Darmoni	E-mail verification	No	MP	France	1 hospital	HOROPLAN
Dowland	E-mail verification	No	H	United Kingdom	1 hospital	
Meyer auf'm Hofe	E-mail verification	Yes	MP	Germany	150 hospitals	ORBIS Dienstplan
Bard	E-mail verification	Yes	H	United States	Commercial product	Care Systems Inc.
Burke	E-mail verification	Yes	H	Belgium	40+ hospitals, beginning implementation in UK	PLANE
Cheng	E-mail verification	Unknown	MP	Hong Kong	1 ward/unit	
Diaz	E-mail verification	Yes	H	Brazil	1 hospital	
Isken	E-mail verification	Partially	H	United States	1 hospital	
Kawanaka	E-mail verification	Yes	H	Japan	Some hospitals	
Kostreva	E-mail verification	Yes	H	United States	1 hospital	
Van Wezel	E-mail verification	Yes	DS	The Netherlands	Multiple hospitals	ZKR-nurse-scheduling support system

Kellogg and Walczak (2007) *Nurse Scheduling: From Academia to Implementation or Not?*, *Interfaces* 37(4): 355-369

Not ready yet

Current practice

Iterative academic approach

- Relevant, attractive problems
- Tailored algorithms

Terminology

Personnel scheduling

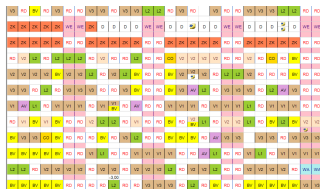
Distribute **shifts** over the **qualified members of staff** in order to meet the **coverage requirements**, taking into account legal and contractual **constraints** and personal **preferences**.



Time

- **scheduling horizon:** 4 weeks, 1 month, 13 weeks, ... constraints across subsequent horizons?
- **cyclic**, semi cyclic, non cyclic schedules
- **shift types**
start- and end time, overlapping shifts, deviating hours, interrupted duties

shift type	from	till
early	7:00	15:00
day	8:00	17:00
late	13:00	21:00
night	21:00	7:00



Personnel

- **skills**
training, experience, responsibility, job description, multiple skills
- **contracts**
full time, part time (x %), night nurse, weekend nurse, etc.



Naam	Minimaal	Ma	Ti	We	Do	Vr	Za	Zo	Ma	Ti	We	Do	Vr	Za	Zo	Ma	Ti	We	Do	Vr	Za	Zo	
APPOUITS LUC	80.00%	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE
APPOUITS MARLA	100.00%	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K
BARTELS CHRISTHAAR	75.00%	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K	2K
BREUGNOTHANS KRISTINE	80.00%	RD	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE
CHARDONHOUTS SOFIE	75.00%	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF
DIMPELRECHTS CHRISTIANA	80.00%	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE
FLOREN JOSIE	100.00%	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1	V1
GORS ELLEN	75.00%	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
JANSENS ROSETTE	50.00%	AF	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE
SCHROEDY ANNA	100.00%	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
STES AN	75.00%	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE	VE
STOFFELS JELLE	50.00%	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF	AF
VAN DEN ABEELE SABINE	100.00%	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF	1AF

Personnel

- **skills ... change over time**
training, experience, responsibility, job description multiple skills
- **contracts ... change over time**
full time, part time (x %), night nurse, weekend nurse, etc.



Naam	Informatie	Dagen														
		Ma	Ti	Wo	Do	Vr	Za	Zu	Ma	Ti	Wo	Do	Vr	Za	Zu	
ARVOULTS LEBE	50,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
ARVOULTS ISENIA	100,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
BARTELS CHRISTIAKE	75,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
BRUJULIAUS KRISTINE	80,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
BRUJULIAUS KRISTINE	75,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
CAMPENMITS ROSE	100,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
EMBRICHTS CHRISTIANA	50,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
FLOREN JOSÉE	100,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
FLOREN JOSÉE	75,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
GOIRS ELLEN	80,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
JAARDENS ROSETTE	80,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
KOENIGX ANNA	100,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
KOENIGX ANNA	75,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
STES AN	50,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
STOFFELS JILLIE	50,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
VAN DEN ARBELE SABINE	100,00%	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
Overzicht Functie - Pleegtype																
Code	Profiel	Ma	Ti	Wo	Do	Vr	Za	Zu	Ma	Ti	Wo	Do	Vr	Za	Zu	
HOOFD VERPLEEGKNOG		0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
VERPLEEGKNOG		0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
OPZICHTER		0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Constraints

- **legal constraints**
e.g. minimum rest time
hard constraints?
- **organisational constraints**
e.g. no skill downgrading
hard constraints?
- **contractual constraints**
e.g. maximum 6 nights per month
- **personal constraints/preferences**
e.g. free Wednesday afternoons



Any feasible solution to the problem?

Evaluation of solutions

	Mo	Tu	We	Th	Fr	Sa	Su		Mo	Tu	We	Th	Fr	Sa	Su
P1						M	M		M	M	L	L	N		
P2	M	L	L				N		N		N	L	L		
P3			L	L					M	M	M	M	M	M	M
P4						L	L		M		L	N	N	N	
P5	N	N	N	N	N				M L	L	L				

Constraint classes

Counters e.g. number of working days

$$v(dw_{e,D'}) = csv(dw_{e,D'}) + \sum_{d \in D'} p_{e,d}$$

Series e.g. number of consecutive days worked

$$p(dw_{e}) = w(dw_{e}) \sum_{d \in D} \max \left\{ \left(\sum_{i=0}^{m(dw_{e})} p_{e,d+i} \right) - m(dw_{e}), 0 \right\}$$

Successive series e.g. number of free days after night shifts

Conditional constraint.

P. Smet et al. (to appear) *Nurse rostering: a complex example of personnel scheduling with perspectives*, *Automated Scheduling: Real World Case Studies*, Springer

Consistent constraint evaluation

- **constraint definition** work stretches or patterns?
- **continuity of series constraints** regardless of the scheduling period (previous and upcoming planning period)
- **contextual evaluation** of constraints

Example 1: Counters

Counter penalty

proportional to the constraint violation ... context?

- Employee request
5 free days starting on Feb 1 for a ski vacation
- Grant either all days or not any at all

Naam	Informatie	Ma 18	Di 19	Wo 20	Do 21	Vr 22	Za 23	Zo 24	Ma 25	Di 26	Wo 27	Do 28	Vr 29	Za 30	Zo 31	Ma 01	Di 02	Wo 03	Do 04	Vr 05	Za 06	Zo 07
A	E	80,70%	V1	V1	V1	V1	V2		V1	V2	V2	V2	V1	L1	L1	BV	BV	BV	BV	BV	V1	V1
		9 BF 60,09%																				
A	E	60,09%		L1	V2	V2		L1	V2	L1			V2				L2	L2		L2		
		5 BF 60,09%																				
B	K	60,09%	L1		V1	V1		V3	V1			L2	L1			V1			L2		L2	L1
		5 BF						V2														

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A	E	80,70%	V1	V1	V1	V2			V1	V2	V2	V2	V1	L1	L1	BV	BV	BV	BV	BV	V1	V1
		9 BF 60,09%																				
A	E	5 BF 60,09%		L1	V2	V2		L1	V2	L1			V2				L2	L2		L2		
B	K	5 BF 60,09%	L1		V1	V1		V3	V1			L2	L1			V1			L2		L2	L1

Example 2: Series

- weekdays: Mon - Fri
- weekend days: Fri - Mon
- weekend constraint:
work full weekends

Fri	Sat	Sun	Mon	
E	E	E	E	
E	E	E		X
	E	E	E	X
E		E	E	X
E	E		E	X
E	E			X
E		E		
E			E	X
	E	E		X
	E		E	X
		E	E	X
E				X
	E			X
		E		X
			E	X

Example 3: Successive series

Overtime

Overtime should be compensated within the next three months.

Interpretation?

1. start counting from the first minute of overtime
2. start counting from the shift assignment causing overtime
3. start counting from the first Monday after the minute/shift causing overtime
4. do not allow additional overtime before the previous overtime has been compensated ... or not?

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Example 3: Successive series

Overtime

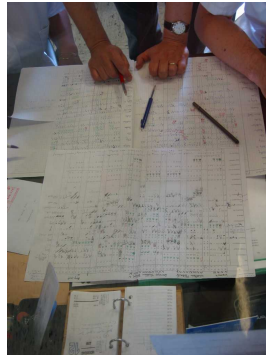
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Interpretation?

1. start counting from the first minute of overtime
2. start counting from the shift assignment causing overtime
3. start counting from the first Monday after the minute/shift causing overtime
4. do not allow additional overtime before the previous overtime has been compensated ... or not?

Accurate data

- hard vs. soft constraints
 - constraint weights
 - implicit preferences
-
- agreement on the data description



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The main goal of CTIT is to create datasets for high-level processing, apart from this, CTIT can create datasets for low-level processing of individual or groups of datasets. For this we have the website [Data](#) on [JSTOR](#), we look at the history of the [dataset](#).

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Quality of a solution

- monetized objectives
- weighted constraint violations

Weighted sum

$$WO = \sum_{\forall n \in N} \sum_{\forall c \in C} \#violations_{n,c} * weight_c$$

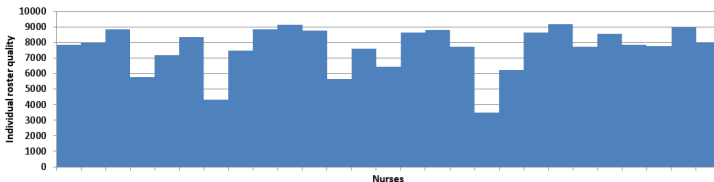
- compensations? unfair objectives, fair variants? fairness measures?

Fairness measures

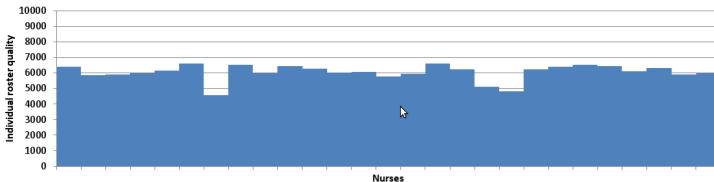
$$\begin{aligned}FO &= \max_n(q_n) \\GO &= q_{avg} + \sum_{n \in N} (|q_{avg} - q_n|) \\RO &= q_{avg} + \max_n(q_n) - \min_n(q_n)\end{aligned}$$

Weighted sum vs. fairness objectives

Individual roster quality with weighted sum objective function

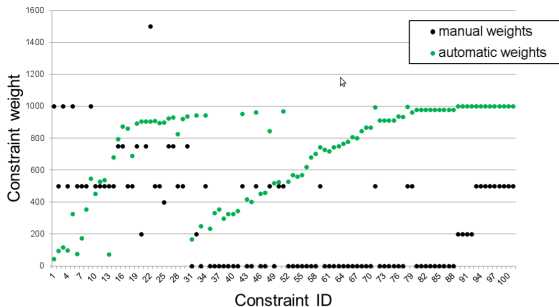


Individual roster quality with alternative objective function for fairness



Constraint weights

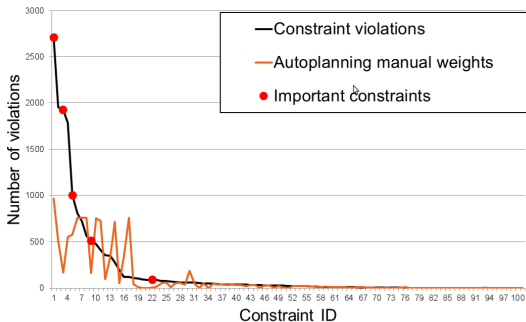
Manual vs. Automatic weights



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Constraint weights

Violations of automatic schedules with manual weights



16/18

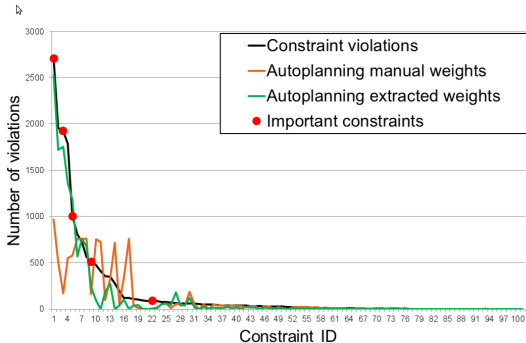
joint work with Mihail Mihaylov and Pieter Smet

KU LEUVEN



Constraint weights

Violations of automatic schedules: manual vs. extracted weights



17/18

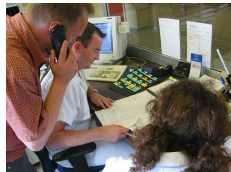
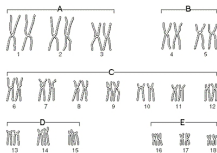
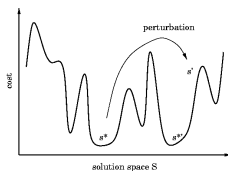
joint work with Mihail Mihaylov and Pieter Smet

Algorithmic trends

$$\sum_{c \in C} w_c n_c$$

$$-|S| |K| p_{e,d} + \sum_{s \in S} \sum_{k \in K} x_{e,d,s,k} \leq 0$$

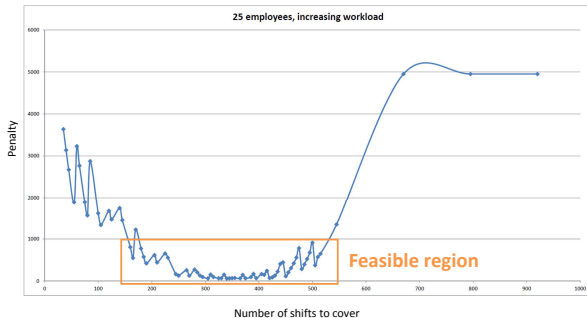
$$-p_{e,d} + \sum_{s \in S} \sum_{k \in K} x_{e,d,s,k} \geq 0$$



Float nurses

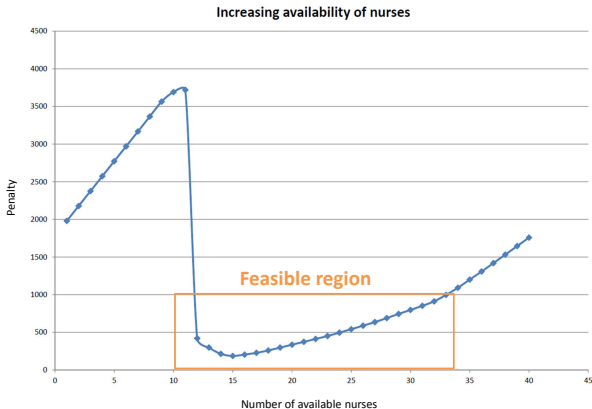
What is the problem with a pool of float nurses?

Workload vs. available staff



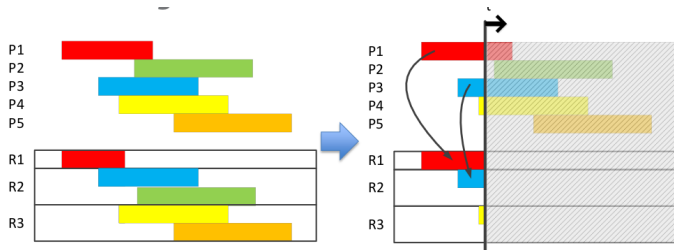
Stefaan Haspeslagh, PhD, 2012

Workload vs. available staff



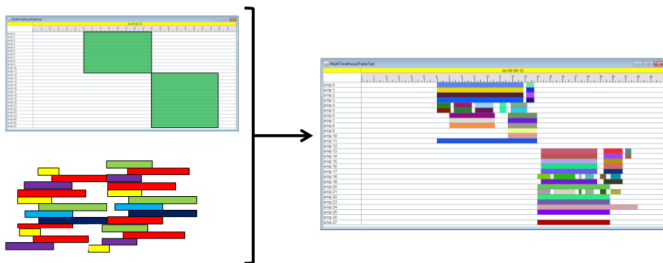
Stefaan Haspeslagh, PhD, 2012

Workload



Wim Vancroonenburg

Tasks vs. shifts



Pieter Smet

Decision levels

- interaction with **manpower planning, staffing**
- quality of solutions cannot be evaluated without information about the quality of solutions at the other levels

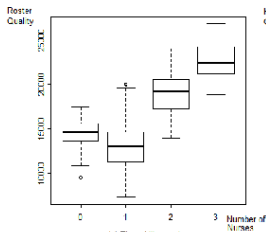
Staffing - scheduling

Ward		Skill 1	Skill 2	Skill 3	Skill 4	Total Nurse
Emergency	Primary skill	1	16	4	6	27
	Secondary skill				20	

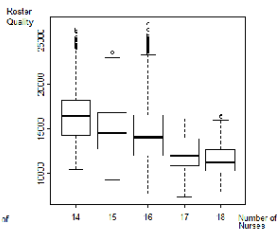
Subgroup	Pattern (Primary skill – secondary skill)	No Of Nurses
Subgroup 1 (G ₁)	Skill 1	1
Subgroup 2 (G ₂)	Skill 2 – Skill 4	16
Subgroup 3 (G ₃)	Skill 3 – Skill 4	4
Subgroup 4 (G ₄)	Skill 4	6
	Total	27

Komarudin

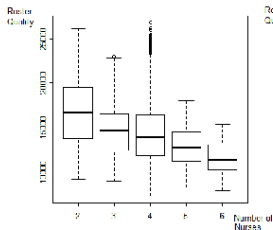
Experimental results



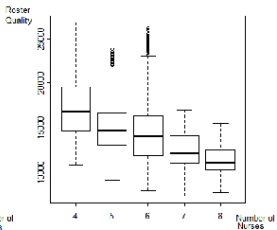
(a) First skill type 1



(b) First skill type 2



(c) First skill type 3



(d) First skill type 4

Why difficult?

personnel schedulers have been doing it manually for years, why would it be difficult to address the problem with a suitable optimisation approach?

- complexity?
- computation time?
- collection of correct information?
- consistent evaluation of the quality?



A hard problem

automated personnel scheduling

- model: correct and sufficiently generic
- algorithm: produce an acceptable solution

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