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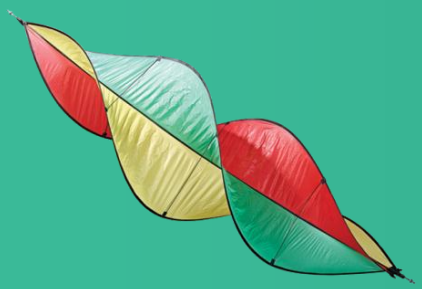


NURSE ROSTERING
Focus on models or algorithms?

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

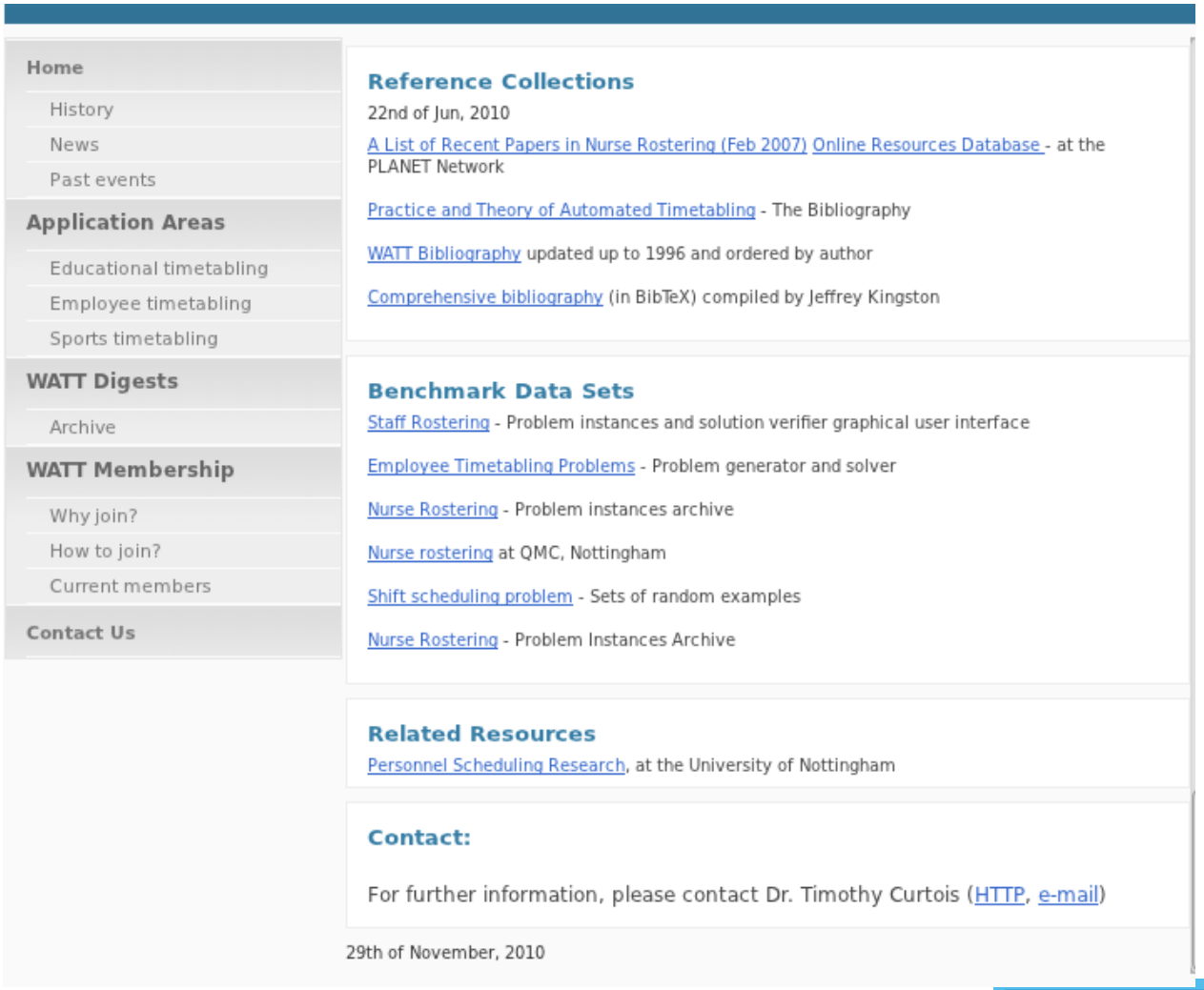
J. Van den Bergh, J. Beliën, P. De Bruecker, E. Demeulemeester, L. De Boeck (2013), Personnel scheduling: A literature review

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.

Datasets


WATT -- EURO Working Group On Automated TimeTabling
Home
History
News
Past events
Application Areas
Educational timetabling
Employee timetabling
Sports timetabling
WATT Digests
Archive
WATT Membership
Why join?
How to join?
Current members
Contact Us
Reference Collections
22nd of Jun, 2010
A List of Recent Papers in Nurse Rostering (Feb 2007) Online Resources Database - at the PLANET Network
Practice and Theory of Automated Timetabling - The Bibliography
WATT Bibliography updated up to 1996 and ordered by author
Comprehensive bibliography (in BibTeX) compiled by Jeffrey Kingston
Benchmark Data Sets
Staff Rostering - Problem instances and solution verifier graphical user interface
Employee Timetabling Problems - Problem generator and solver
Nurse Rostering - Problem instances archive
Nurse rostering at QMC, Nottingham
Shift scheduling problem - Sets of random examples
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

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

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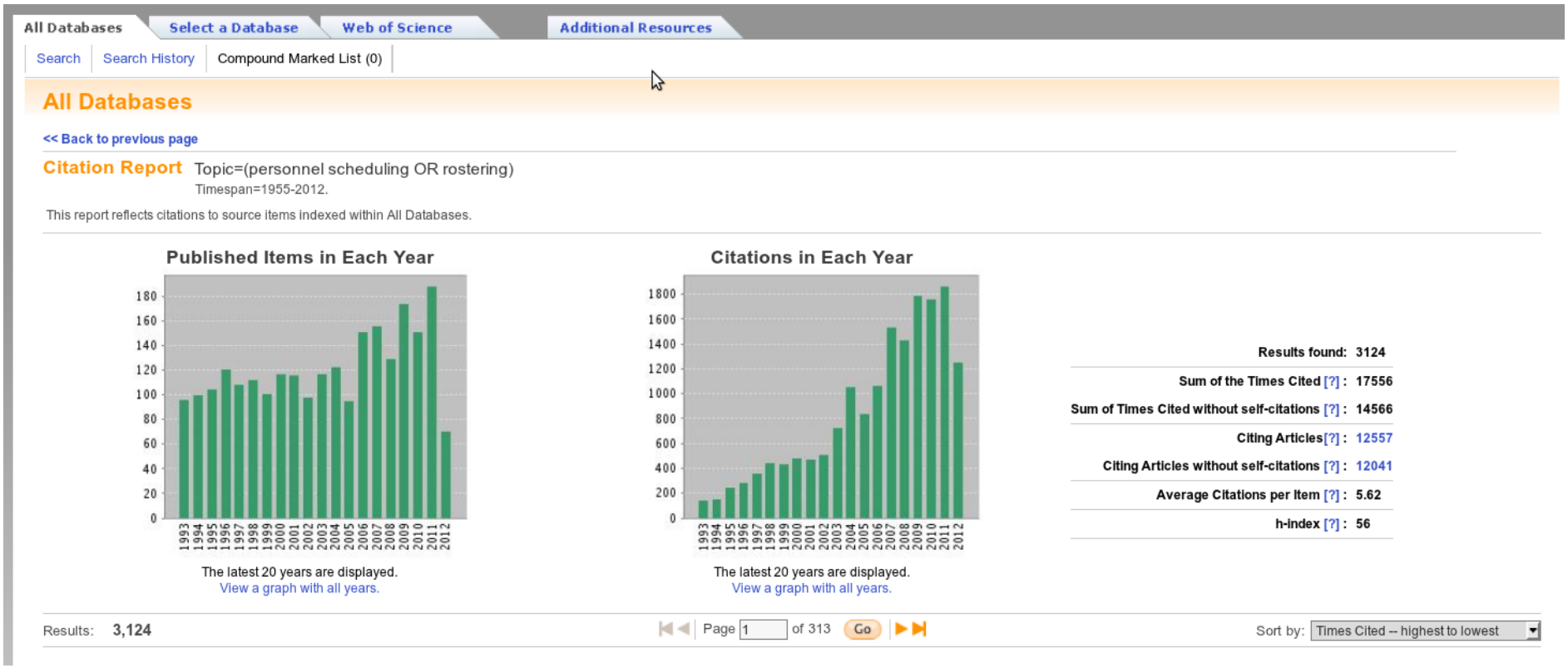
Web of Knowledge



10 most cited papers

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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
Source: JOURNAL OF HEURISTICS Volume: **9** Issue: **6** Pages: **451-470** DOI: **10.1023/B:HEUR.0000012446.94732.b6** Published: **DEC 2003**

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: **10.1097/00000542-199501000-00013** 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/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: **Aussois, 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**

KU LEUVEN KAHO KAHO SINT-LIEVEN

Where is the theory?

Vehicle routing

TRANSPORTATION SCIENCE
Vol. 43, No. 4, November 2009, pp. 408–416
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DOI 10.1287/trsc.1090.0301

Fifty Years of Vehicle Routing

Gilbert Laporte
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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.

KU LEUVEN KAHO KAHO SINT-LIEVEN

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)
$1\|p_i=p;r_i\|\sum w_iC_i$	Baptiste (2000)
$1\|sp-graph\|\sum w_iC_i$	Lawler (1978)
$1\|r_i;pmtn\|\sum U_i$	Lawler (1990)
$1\|p_i=p;r_i\|\sum w_iU_i$	Baptiste (1999)
$1\|pmtn;p_i=p;r_i\|\sum w_iU_i$	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)
$1\|p_i=1;r_i\|\sum w_iT_i$	Assignment-problem

- **maximal pseudopolynomially solvable:**

$1\|r_i;pmtn\|\sum w_iU_i$	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)
*	$1\|chains;p_i=1;r_i\|\sum w_iC_i$	Lenstra & Rinnooy Kan (1980)
*	$1\|prec;p_i=1\|\sum w_iC_i$	Lawler (1978), Lenstra & Rinnooy Kan (1978)
*	$1\|r_i;pmtn\|\sum w_iC_i$	Labetoulle et al. (1984)

KAHO SINT-LIEVEN

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 rerostering 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

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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
Dowsland	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.

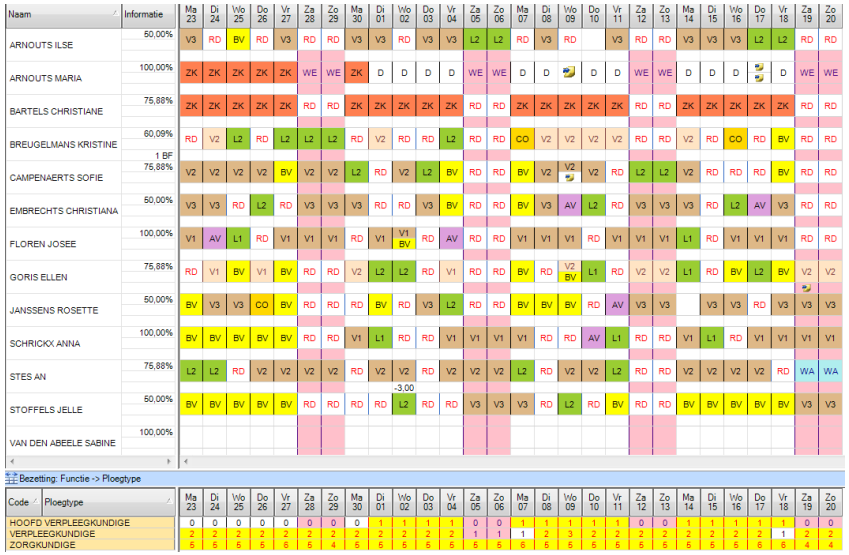
Time

- **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

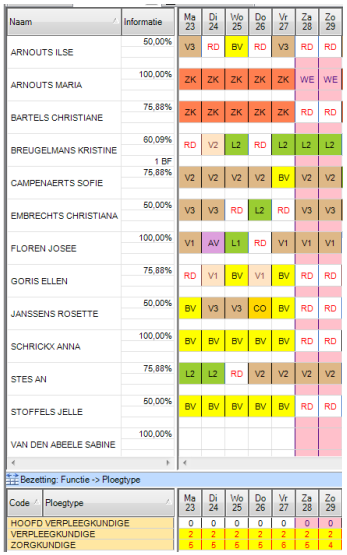
Personnel

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



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.



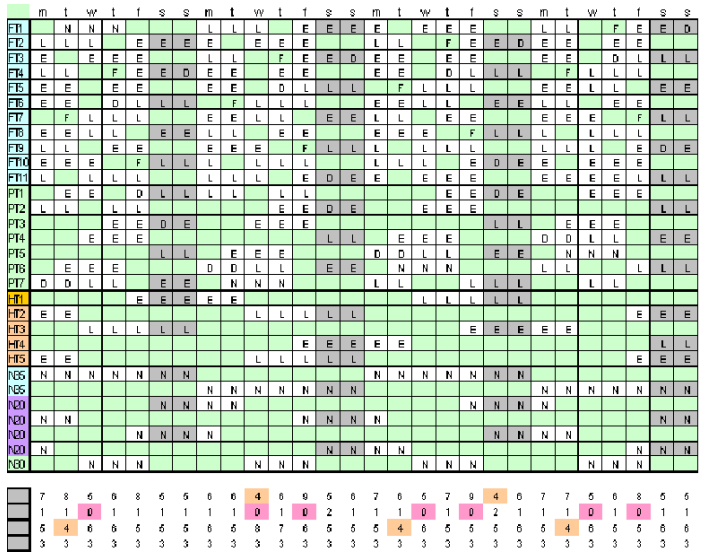
Naam	Informatie	Ma 23	Di 24	Wo 25	Do 26	Vr 27	Za 28	Zo 29
ARNOUTS ILSE	50,00%	V3	RD	BV	RD	V3	RD	RD
ARNOUTS MARIA	100,00%	ZK	ZK	ZK	ZK	ZK	WE	WE
BARTELS CHRISTIANE	75,88%	ZK	ZK	ZK	ZK	ZK	RD	RD
BREUGELMANS KRISTINE	60,09%	RD	V2	L2	RD	L2	L2	L2
CAMPENAERTS SOFIE	1 BF 75,88%	V2	V2	V2	V2	BV	V2	V2
EMBRECHTS CHRISTIANA	50,00%	V3	V3	RD	L2	RD	V3	V3
FLOREN JOSEE	100,00%	V1	AV	L1	RD	V1	V1	V1
GORIS ELLEN	75,88%	RD	V1	BV	V1	BV	RD	RD
JANSSENS ROSETTE	50,00%	BV	V3	V3	CO	BV	RD	RD
SCHRICKX ANNA	100,00%	BV	BV	BV	BV	BV	RD	RD
STES AN	75,88%	L2	L2	RD	V2	V2	V2	V2
STOFFELS JELLE	50,00%	BV	BV	BV	BV	BV	RD	RD
VAN DEN ABEELE SABINE	100,00%							

Bezetting: Functie -> Ploegtype

Code	Ploegtype	Ma 23	Di 24	Wo 25	Do 26	Vr 27	Za 28	Zo 29
HOOFD VERPLEEGKUNDIGE		0	0	0	0	0	0	0
VERPLEEGKUNDIGE		2	2	2	2	2	2	2
ZORGKUNDIGE		5	5	5	5	6	5	4

Coverage requirements

- coverage = number of qualified personnel members per day and per shift type, for the entire scheduling horizon
- minimum coverage hard constraint?
- preferred coverage



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

Constraint classes

Counters e.g. number of working days

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

Series e.g. number of consecutive days worked

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

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																					
A E	60,09%		L1	V2	V2		L1	V2	L1				V2			L2	L2		L2			
	5 BF																					
B K	60,09%	L1		V1	V1		V3	V1				L2	L1			V1			L2		L2	L1
	5 BF						VZ															

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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																					
A E	60,09%		L1	V2	V2		L1	V2	L1				V2			L2	L2		L2			
	5 BF																					
B K	60,09%	L1		V1	V1		V3	V1				L2	L1			V1			L2		L2	L1
	5 BF						VZ															

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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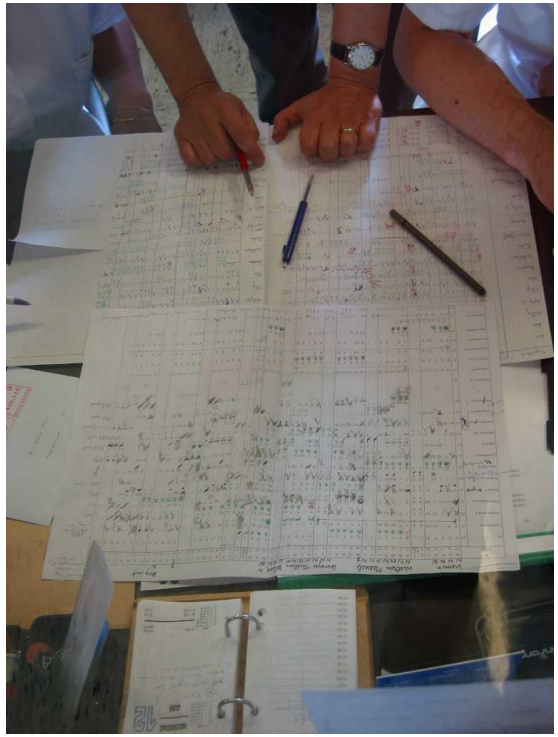
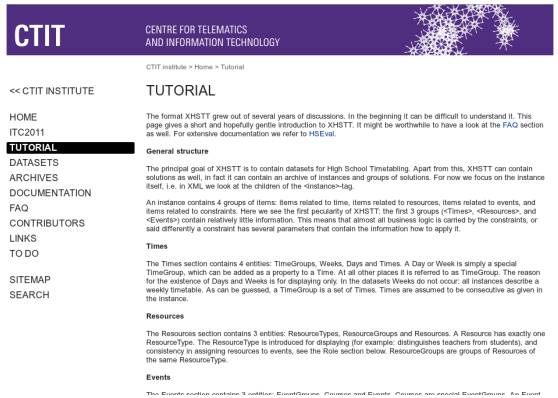
Accurate data

- hard vs. soft constraints
- constraint weights
- implicit preferences



- agreement on the data description



Quality of a solution

- monetized objectives
- weighted constraint violations

Weighted sum

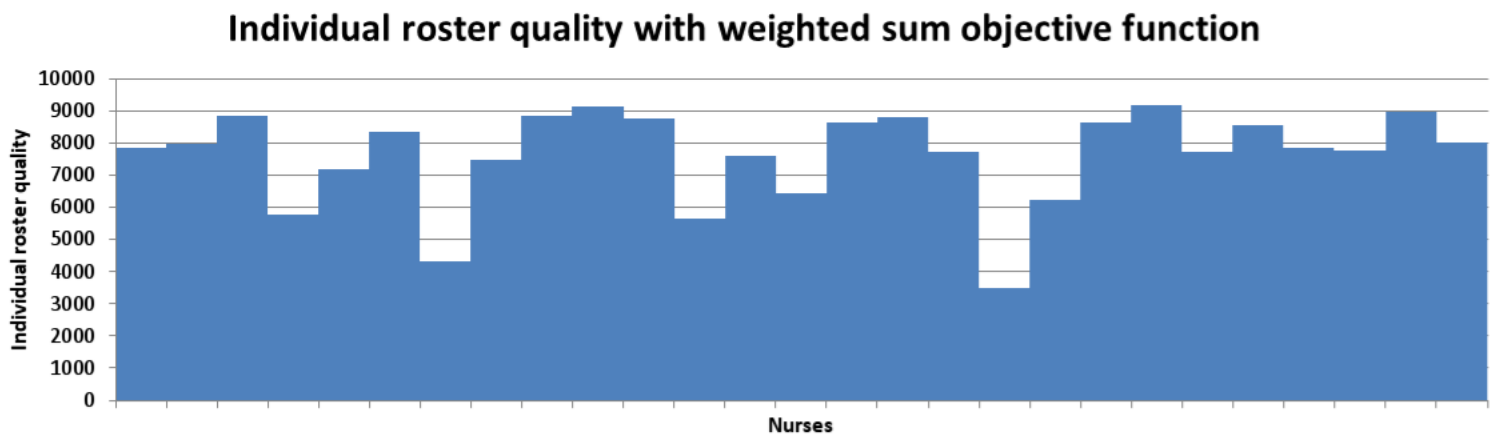
$$WO = \sum_{\forall n \in N} \sum_{\forall c \in C} \#\text{violations}_{n,c} * \text{weight}_c$$

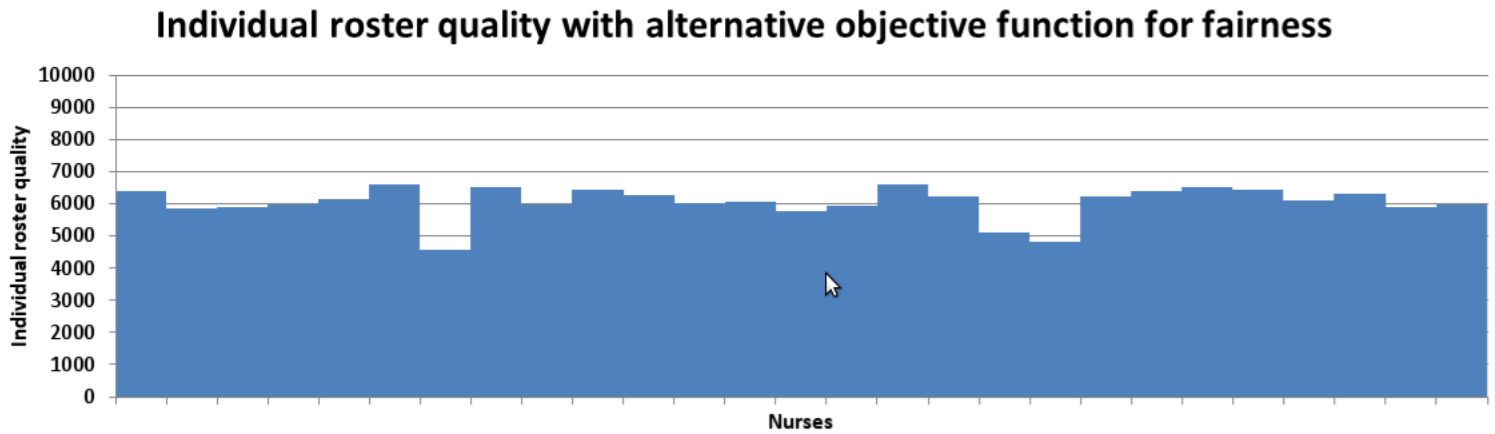
- compensations? unfair objectives, fair variants? fairness measures?

Fairness measures

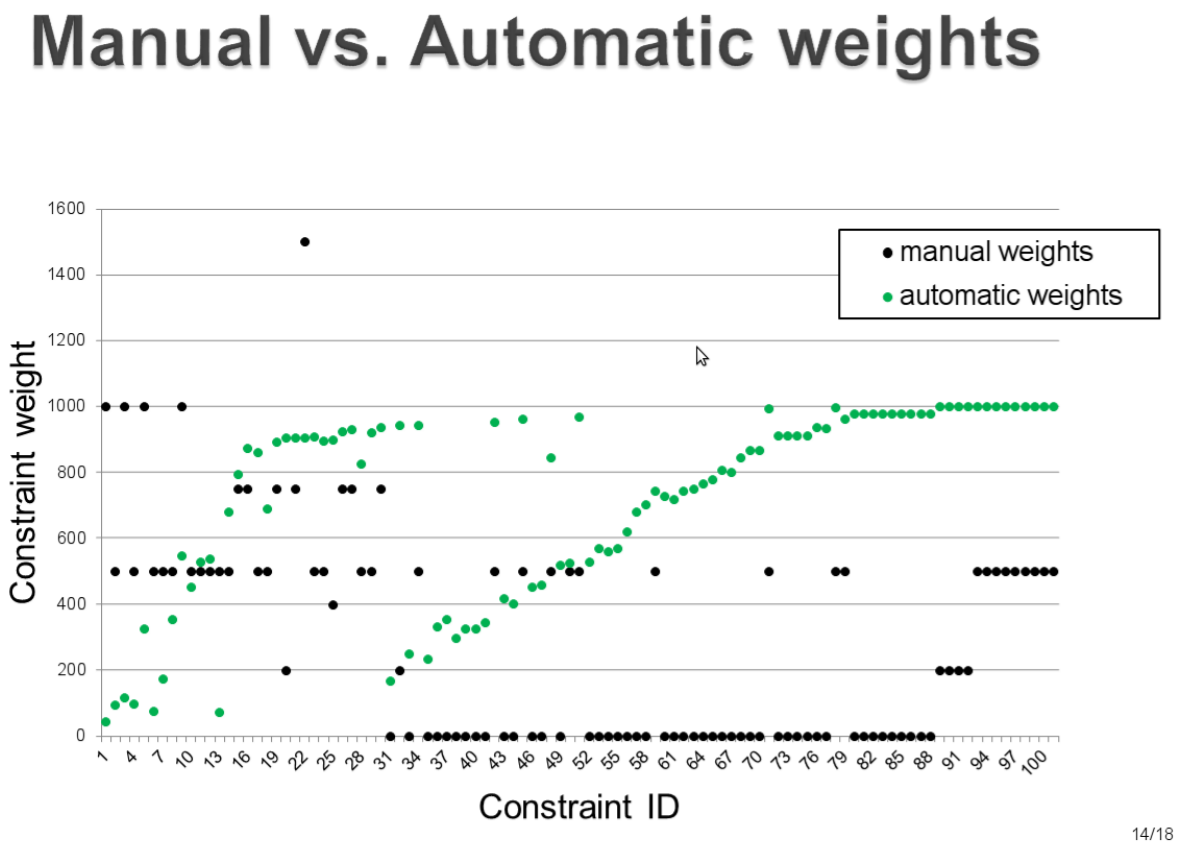
$$FO = max_n(q_n)$$
$$GO = q_{avg} + \sum_{n \in N}(|q_{avg} - q_n|)$$
$$RO = q_{avg} + max_n(q_n) - min_n(q_n)$$

Weighted sum vs. fairness objectives



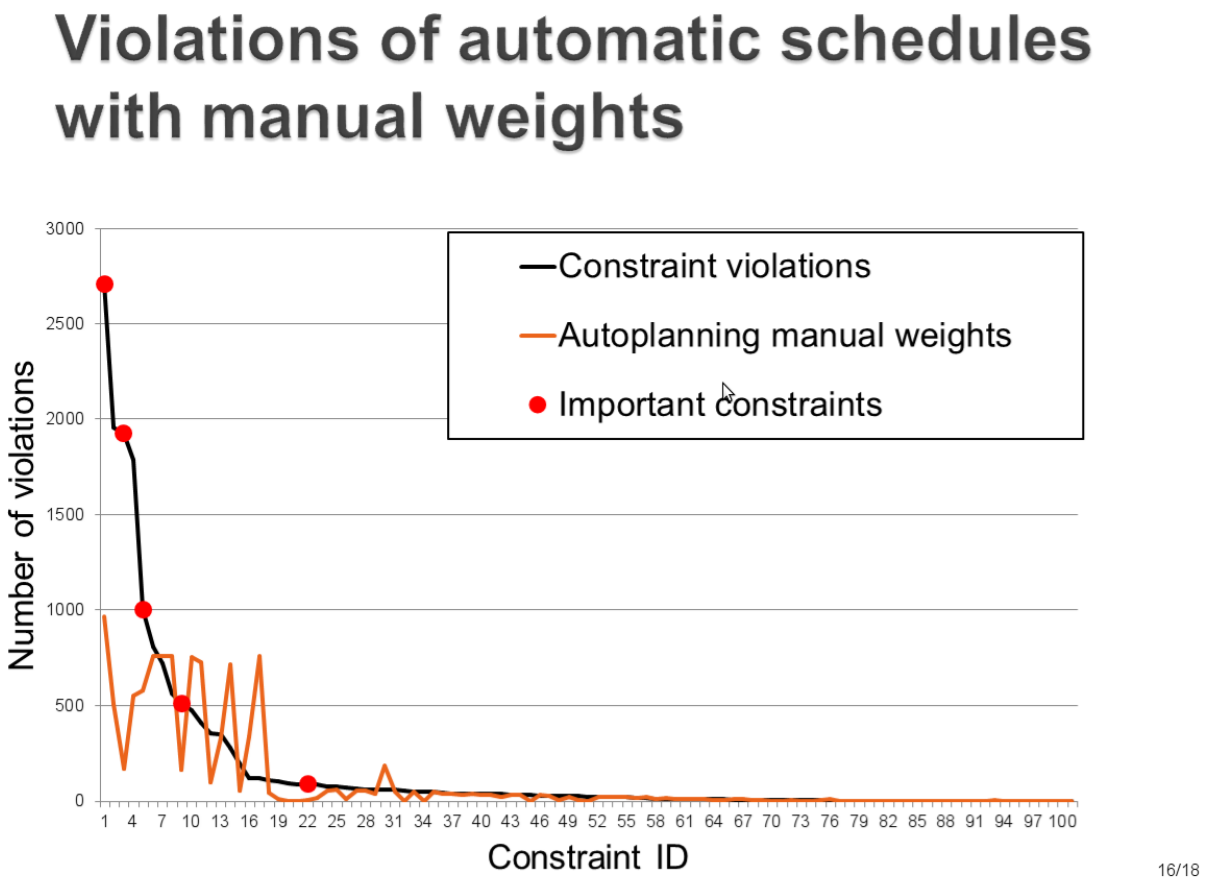


Constraint weights



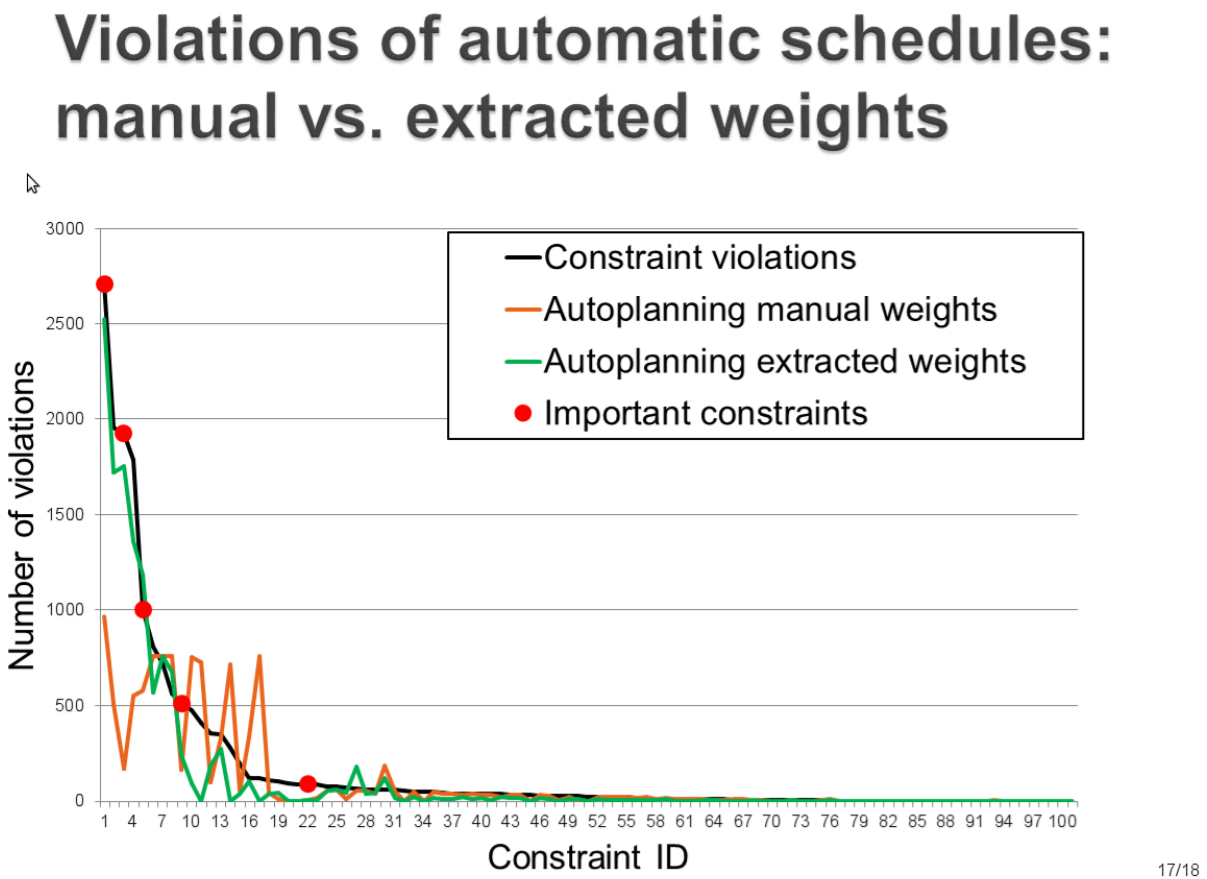
Mihail Mihaylov and Pieter Smet

Constraint weights



joint work with Mihail Mihaylov and Pieter Smet

Constraint weights



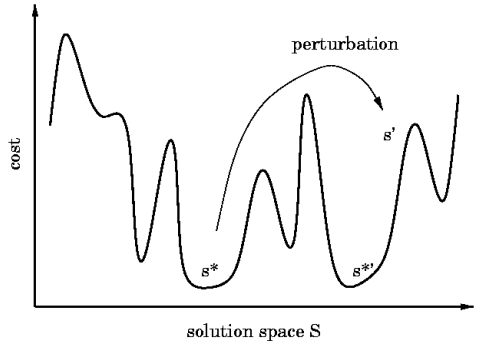
joint work with Mihail Mihaylov and Pieter Smet

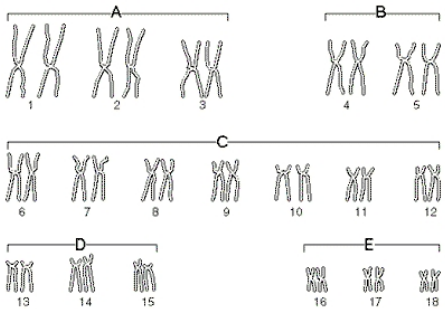
Algorithmic trends

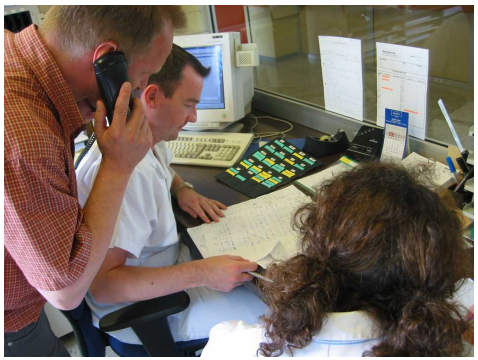
$$\sum_{c \in C} w_c n_c$$

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

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



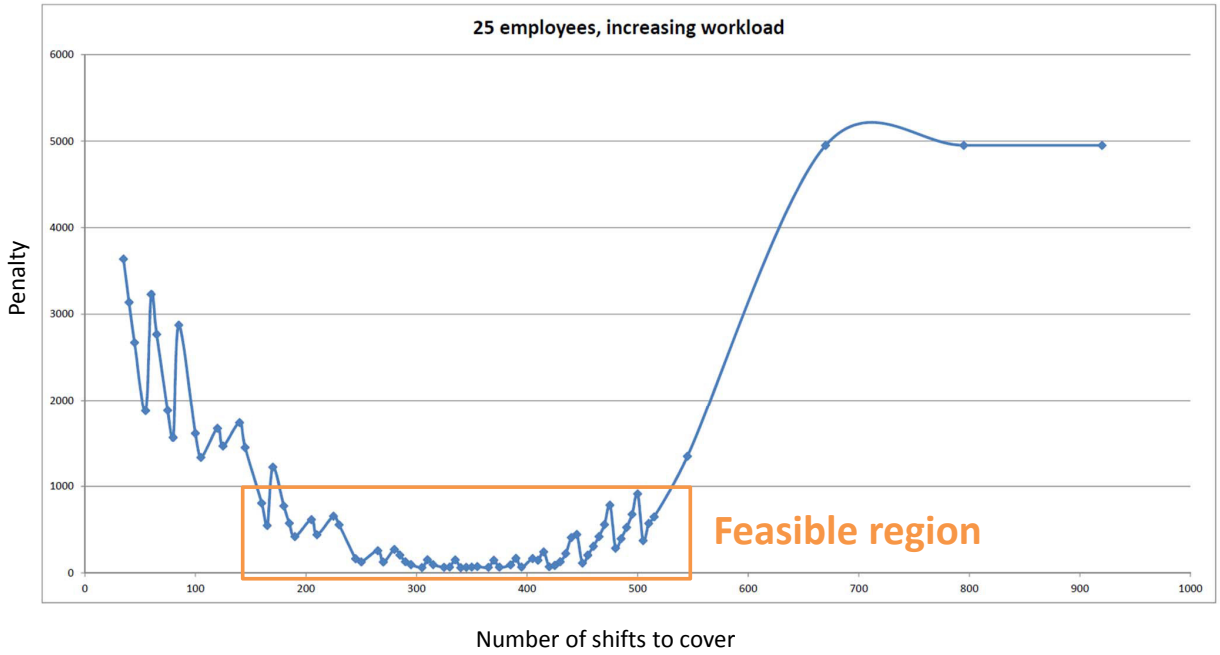




Float nurses

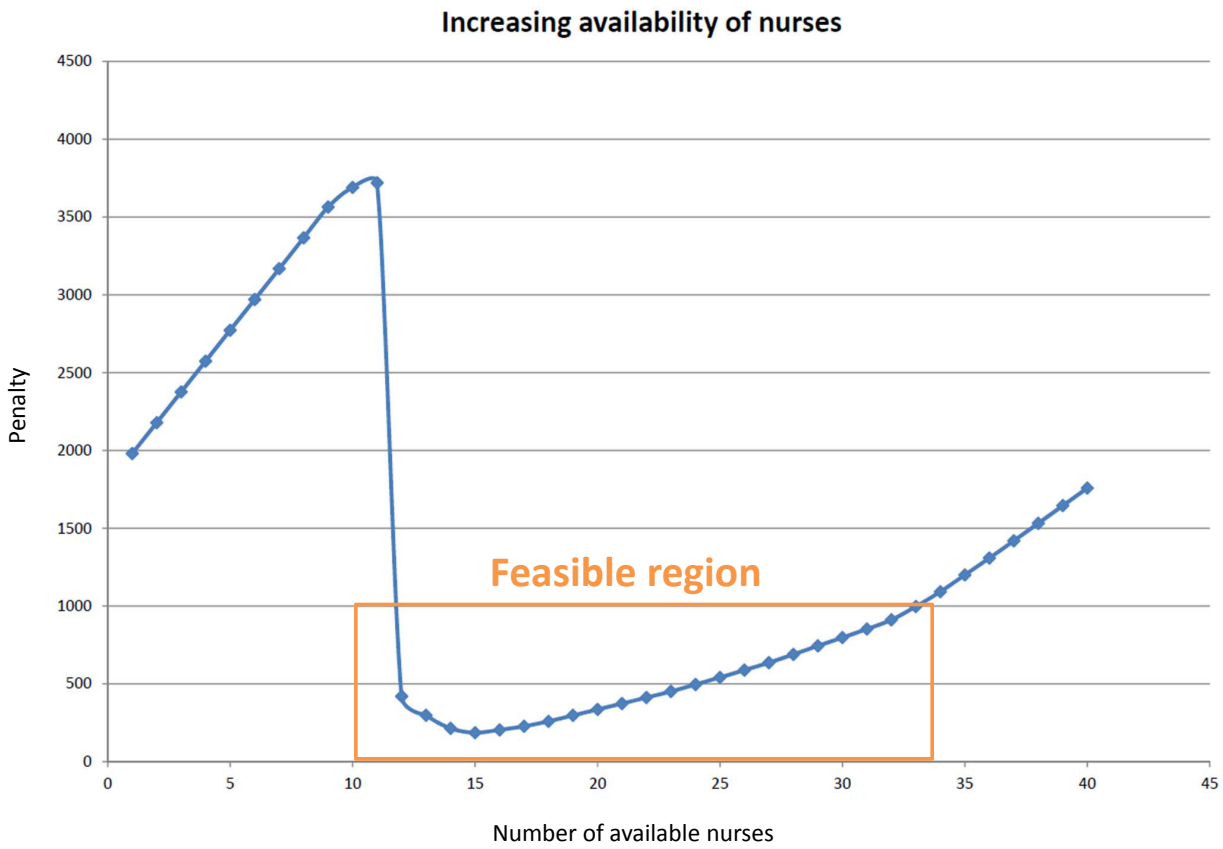
What is the problem with a pool of float nurses?

Workload vs. available staff



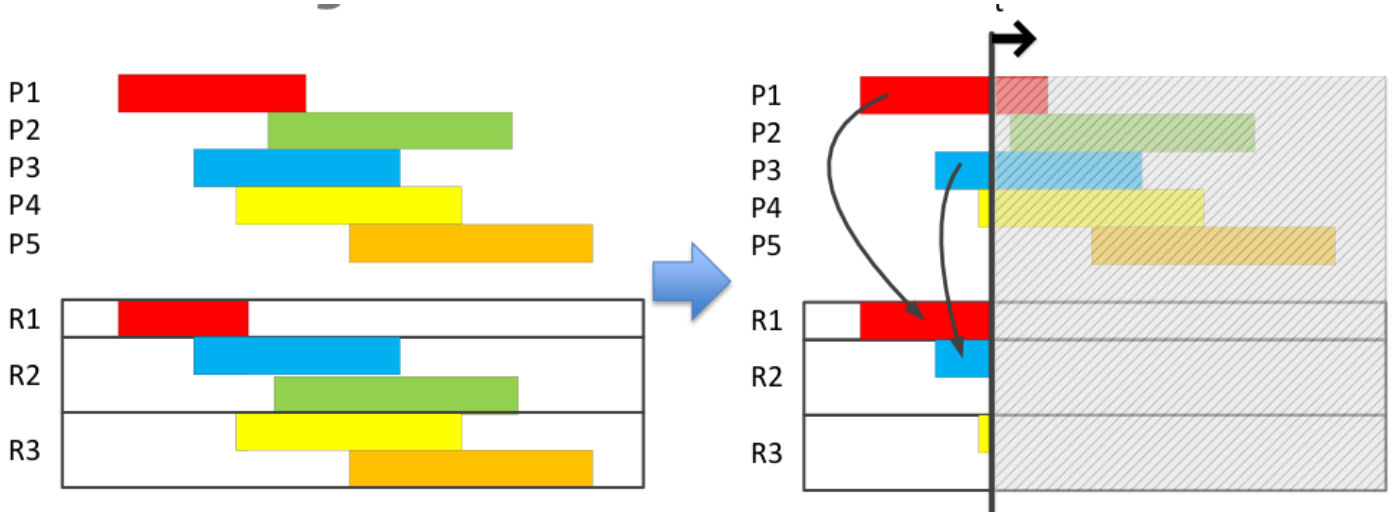
Stefaan Haspeslagh, PhD, 2012

Workload vs. available staff



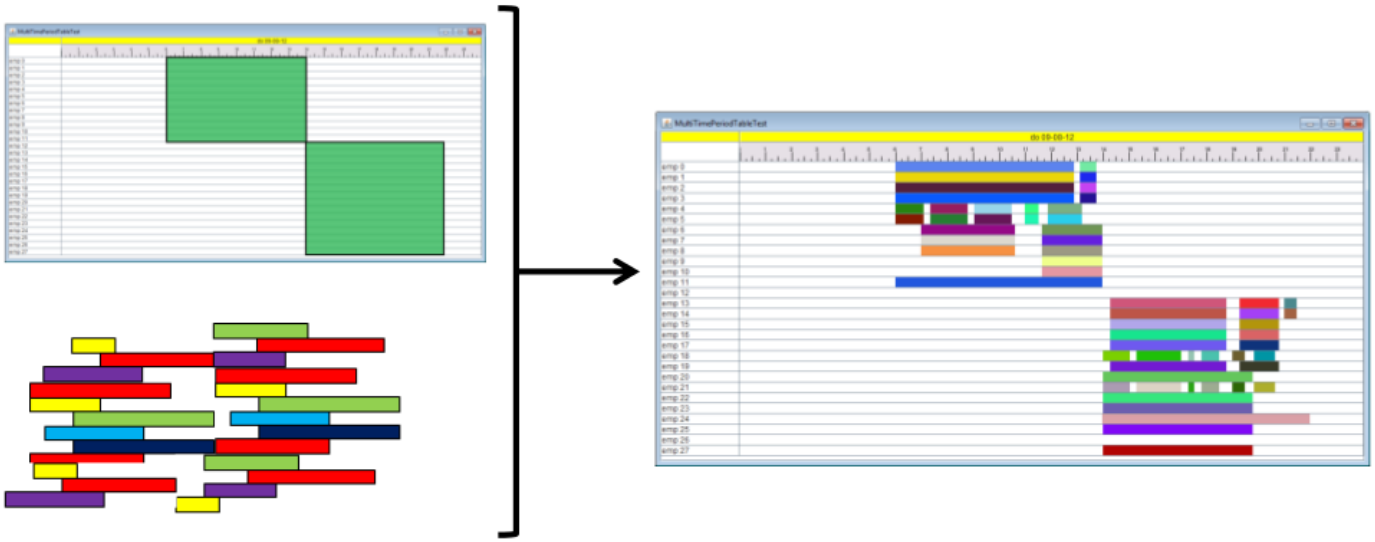
Stefaan Haspeslagh, PhD, 2012

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

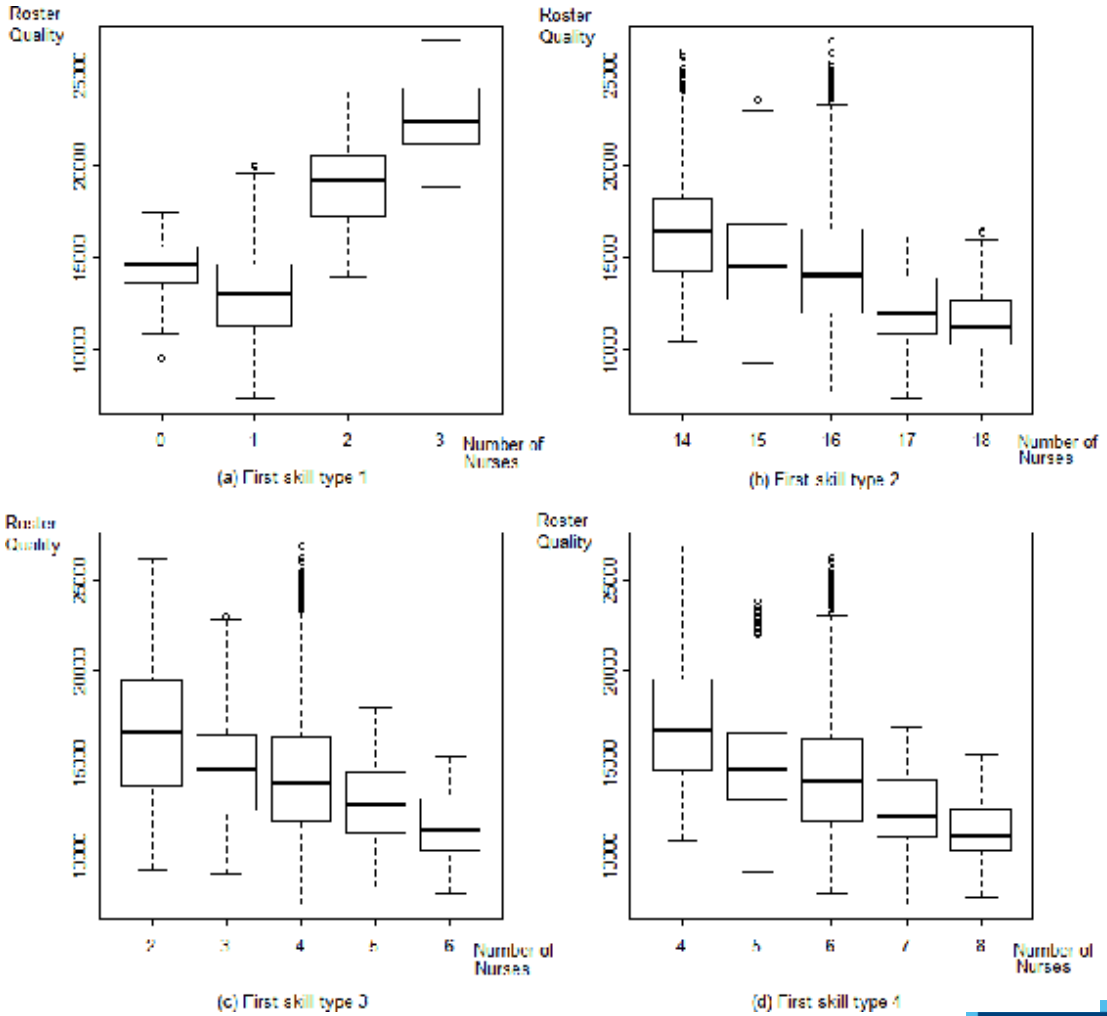
Staffing - scheduling

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

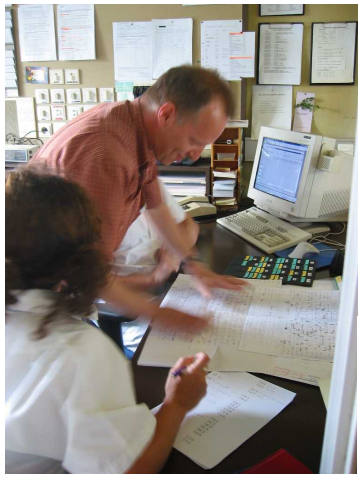
Experimental results

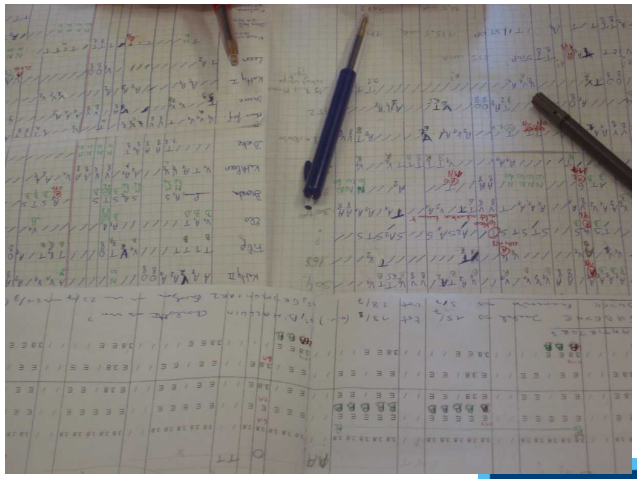


Why difficult?

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

Acknowledgements

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