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Proactive personnel rostering

Generating robust rosters to cope with employee absenteeism

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Outline

1. Personnel rostering
2. Reactive and proactive rostering
3. Quantifying and enforcing roster robustness
4. Data-driven robust rostering

Personnel rostering problems

Context

Workplace absences 'at 10-year high' with stress the major cause of long-term sickness

COVID-19 and cost of living worries are all seen as factors behind a deterioration in workplace wellbeing, according to a study which wants greater support for staff

Stressed out and burned out: Younger nurses feel strain of nursing shortage

Gen Z nurses are far less likely to encourage their peers to go into nursing.

GLOBAL | **GENEVA**

Global truck driver shortage to double by 2028, says new IRU report

20 NOV 2023 · PEOPLE

- Over 3 million truck driver positions are currently unfilled in 36 countries studied

Workers are historically stressed out and disengaged

By Jordan Valinsky, CNN

THE BIG QUESTION

Economy | Business and Economy

Will a four-day work week solve Germany's labour shortage?

Counterintuitively, a new German experiment is testing whether working less can actually help overcome a labour crunch.

Personnel rostering problems

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Employee 1							
Employee 2							
Employee 3							
Employee 4							

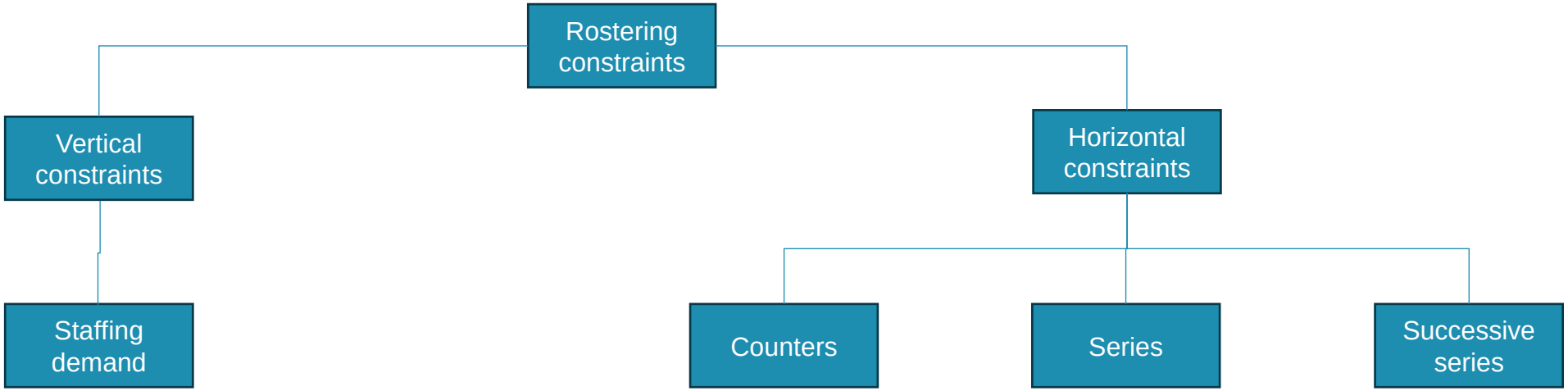
No. of E shifts	0/1	0/1	0/1	0/1	0/1	0/1	0/1
No. of L shifts	0/1	0/1	0/1	0/1	0/1	0/1	0/1
No. of N shifts	0/1	0/1	0/1	0/1	0/1	0/0	0/0

Personnel rostering problems

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Employee 1	E	E	L	L	L		
Employee 2			E	E	E	L	L
Employee 3	L	L		N	N	N	
Employee 4	N	N	N			E	E

No. of E shifts	1/1	1/1	1/1	1/1	1/1	1/1	1/1
No. of L shifts	1/1	1/1	1/1	1/1	1/1	1/1	1/1
No. of N shifts	1/1	1/1	1/1	1/1	1/1	1/0	0/0

Personnel rostering problems



Smet, P., Bilgin, B., De Causmaecker, P., & Vanden Berghe, G. (2014). Modelling and evaluation issues in nurse rostering. *Annals of Operations Research, 218*, 303-326.

Personnel rostering problems

Examples of horizontal rostering constraints

Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed
N	N	N			E	E	L	L	L

- Counter: 5 assignments per week
- Series: max 5 consecutive days worked
- Series: min 2 consecutive days off
- Series: complete and identical weekends
- Successive series : 11 hours rest between two consecutive days worked
- Successive series: min 2 consecutive days off after min 1 N shift worked

Personnel rostering problems

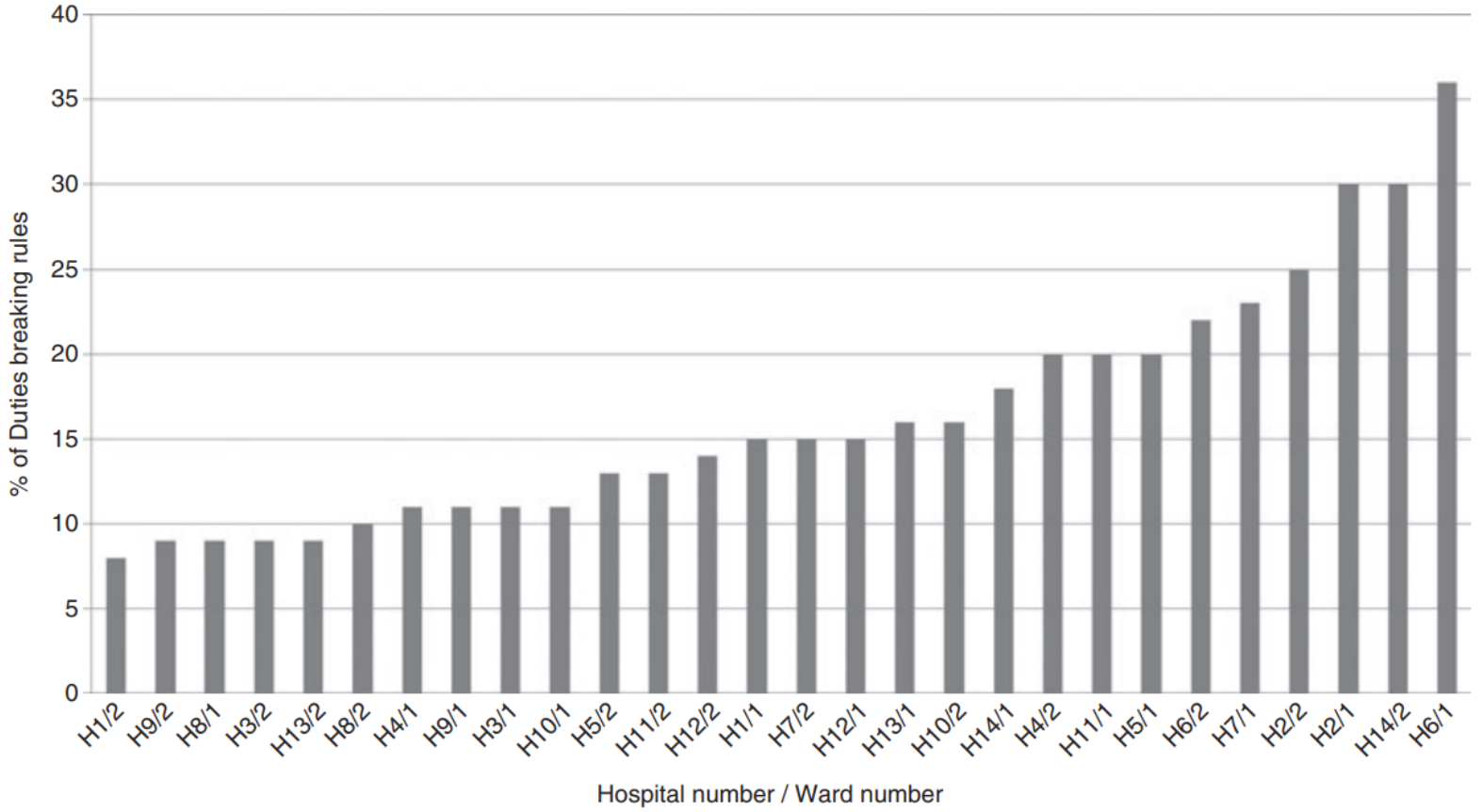


Figure 2 Percentage duties breaking rules in each ward.

Drake, R. G. (2014). The nurse rostering problem: from operational research to organizational reality?. Journal of advanced nursing, 70(4), 800-810.

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Personnel rostering problems

Instance	Weeks	Employees	Shift types	Best known lower bound	Best known solution
Instance1 txt xml	2	8	1	607	**607**
Instance2 txt xml	2	14	2	828	**828**
Instance3 txt xml	2	20	3	1001	**1001**
Instance4 txt xml	4	10	2	1716	**1716**
Instance5 txt xml	4	16	2	1143	**1143**
Instance6 txt xml	4	18	3	1950	**1950**
Instance7 txt xml	4	20	3	1056	**1056**
Instance8 txt xml	4	30	4	1300	**1300**
Instance9 txt xml	4	36	4	439	**439**
Instance10 txt xml	4	40	5	4631	**4631**
Instance11 txt xml	4	50	6	3443	**3443**
Instance12 txt xml	4	60	10	4040	**4040**
Instance13 txt xml	4	120	18	1348	**1348**
Instance14 txt xml	6	32	4	1278	**1278**
Instance15 txt xml	6	45	6	3829	**3829**
Instance16 txt xml	8	20	3	3225	**3225**
Instance17 txt xml	8	32	4	5746	**5746**
Instance18 txt xml	12	22	3	4459	**4459**
Instance19 txt xml	12	40	5	3149	**3149**
Instance20 txt xml	26	50	6	4769	**4769**
Instance21 txt xml	26	100	8	21133	**21133**
Instance22 txt xml	52	50	10	30241	**30241**
Instance23 txt xml	52	100	16	16990	17428
Instance24 txt xml	52	150	32	26571	42463

Instances with up to 50 employees, 10 shift types and a planning period of 1 year solved to optimality!

Dominant algorithms:

- Branch and price
- Metaheuristics (local search, large neighborhood search)

http://www.schedulingbenchmarks.org/nrp/

Reactive and proactive rostering

Reactive rostering

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Employee 1	E	E	E	L	L		
Employee 2			✖	E	E	L	L
Employee 3	L	L	L		N	N	
Employee 4	N	N	N	N		E	E

No. of E shifts	1/1	1/1	**0/1**	1/1	1/1	1/1	1/1
No. of L shifts	1/1	1/1	1/1	1/1	1/1	1/1	1/1
No. of N shifts	1/1	1/1	1/1	1/1	1/1	1/0	0/0

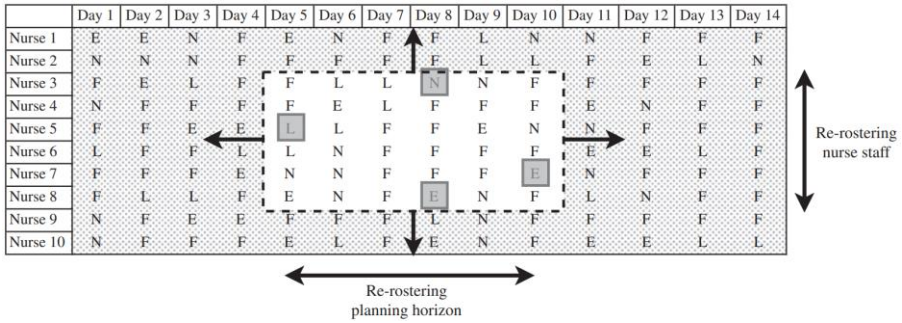
Employee 2 becomes absent on Wednesday.

Chain of repair operations:

1. Assign E to employee 1
2. Assign L to employee 3
3. Unassign N from employee 3 on Thursday
4. Assign N to employee 4 on Thursday

Common elements in reactive rostering:

- Alternative objective function
- Constraint relaxations
- Strategies to limit search space



Maenhout, B., & Vanhoucke, M. (2013). Reconstructing nurse schedules: Computational insights in the problem size parameters. Omega, 41(5), 903-918.

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Proactive rostering

- Reactive rostering negatively impacts employees
  - Worse sleep quality
  - Reduced sleep duration
  - Higher turnover intention

- Better to make robust rosters that can better tolerate variability in employee availability
  →**Proactive rostering**

- Buffers

Djupedal, I. L. R., Pallesen, S., Harris, A., Waage, S., Bjorvatn, B., & Vedaa, Ø. (2022). Changes in the work schedule of nurses related to the COVID-19 pandemic and its relationship with sleep and turnover intention. International Journal of Environmental Research and Public Health, 19(14), 8682.

Proactive rostering

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Employee 1	L	L	L			E	E
Employee 2	E	E	✖	E	E		
Employee 3			E	L	L	L	L
Employee 4	N	N	N	N	N		

No. of E shifts	1/1	1/1	1/1	1/1	1/1	1/1	1/1
No. of L shifts	1/1	1/1	1/1	1/1	1/1	1/1	1/1
No. of N shifts	1/1	1/1	1/1	1/1	1/1	1/0	0/0

Overstaffing for the E shift on Wednesday.

When Employee 2 becomes absent → no change necessary!

Proactive rostering

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Employee 1	L	L	L			E	E
Employee 2	E	E	✖	E	E		
Employee 3			R → E	L	L	L	L
Employee 4	N	N	N	N	N		

No. of E shifts	1/1	1/1	**0/1**	1/1	1/1	1/1	1/1
No. of L shifts	1/1	1/1	1/1	1/1	1/1	1/1	1/1
No. of N shifts	1/1	1/1	1/1	1/1	1/1	1/0	0/0
No. of R shifts	0	0	1	0	0	0	0

Reserve shift R rostered on Wednesday.

When Employee 2 becomes absent → Convert the reserve shift to an E shift!

Proactive rostering

Capacity buffer

	Wed
Employee 1	L
Employee 2	E
Employee 3	E
Employee 4	N

- Part of the regular assignments, no rerostering required
- Can only cover absences for the same shift type

Reserve shift buffer

	Wed
Employee 1	L
Employee 2	E
Employee 3	R
Employee 4	N

- Still requires changes during re-rostering
- Can cover absences for different shift types

Proactive rostering

- Re-rostering operations when using buffers

Operation	Re-rostering cost
Change a shift assignment	Large cost
Call in an interim worker	Very large cost

Quantifying and enforcing robustness in staff rostering

Joint work with Toni Wickert and Greet Vanden Berghe

Wickert, T. I., Smet, P., & Vanden Berghe, G. (2021). Quantifying and enforcing robustness in staff rostering. Journal of Scheduling, 24(3), 347-366.

Generating robust rosters

- Measure roster robustness at different levels of granularity: roster-wide, per day, per shift or per skill
  - 0: none of the working shifts can be replaced
  - 1: all working shifts can be replaced

- Robustness from reserve shift buffers on day *d:*

$$\widehat{r_d} = \frac{\text{Number of reserve shifts assigned on day } d}{\text{Number of working shifts assigned on day } d}$$

- Use integer programming to generate rosters according to a given robustness level.

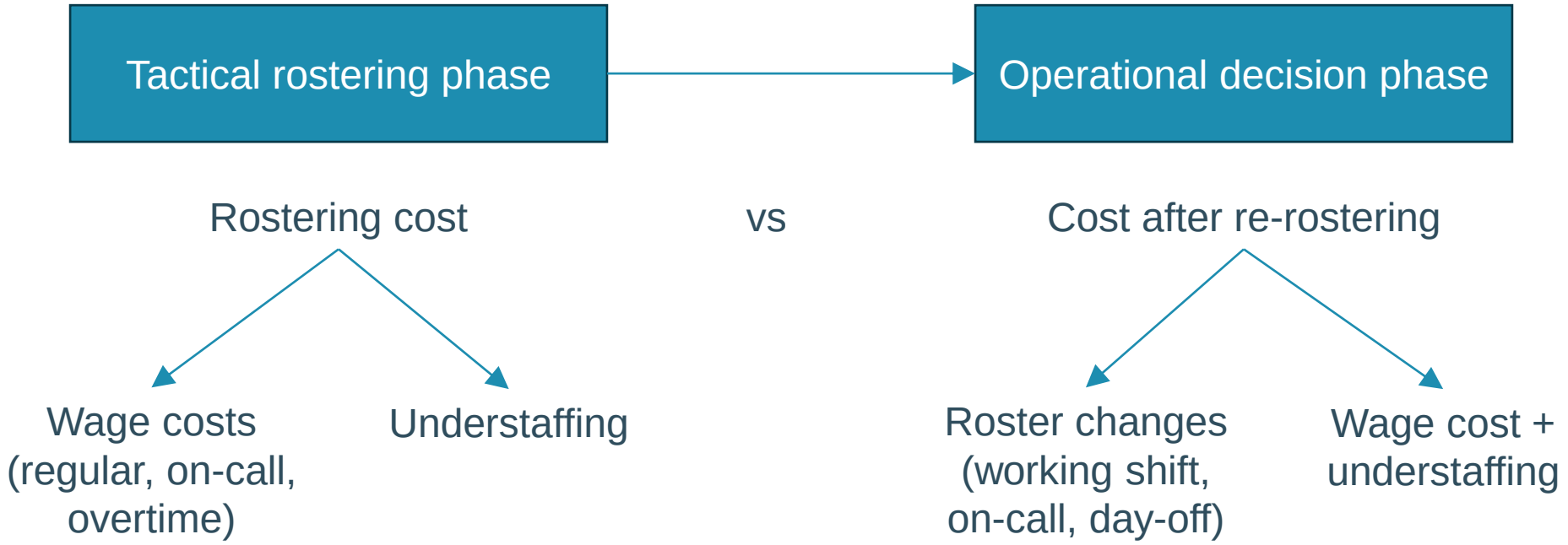
- When is it no longer beneficial to increase roster robustness?

Computational study

- Data from the second International Nurse Rostering Competition
  - 35 employees
  - 28 days
  - 4 regular shift types
- Employees without skills and skilled employees with hierarchical substitution
- Generate and re-roster 100 absence scenarios
- Robustness levels: 0.0%, ≥ 2.5%, ≥ 5.0%, ≥ 7.5%, ≥ 10.0%

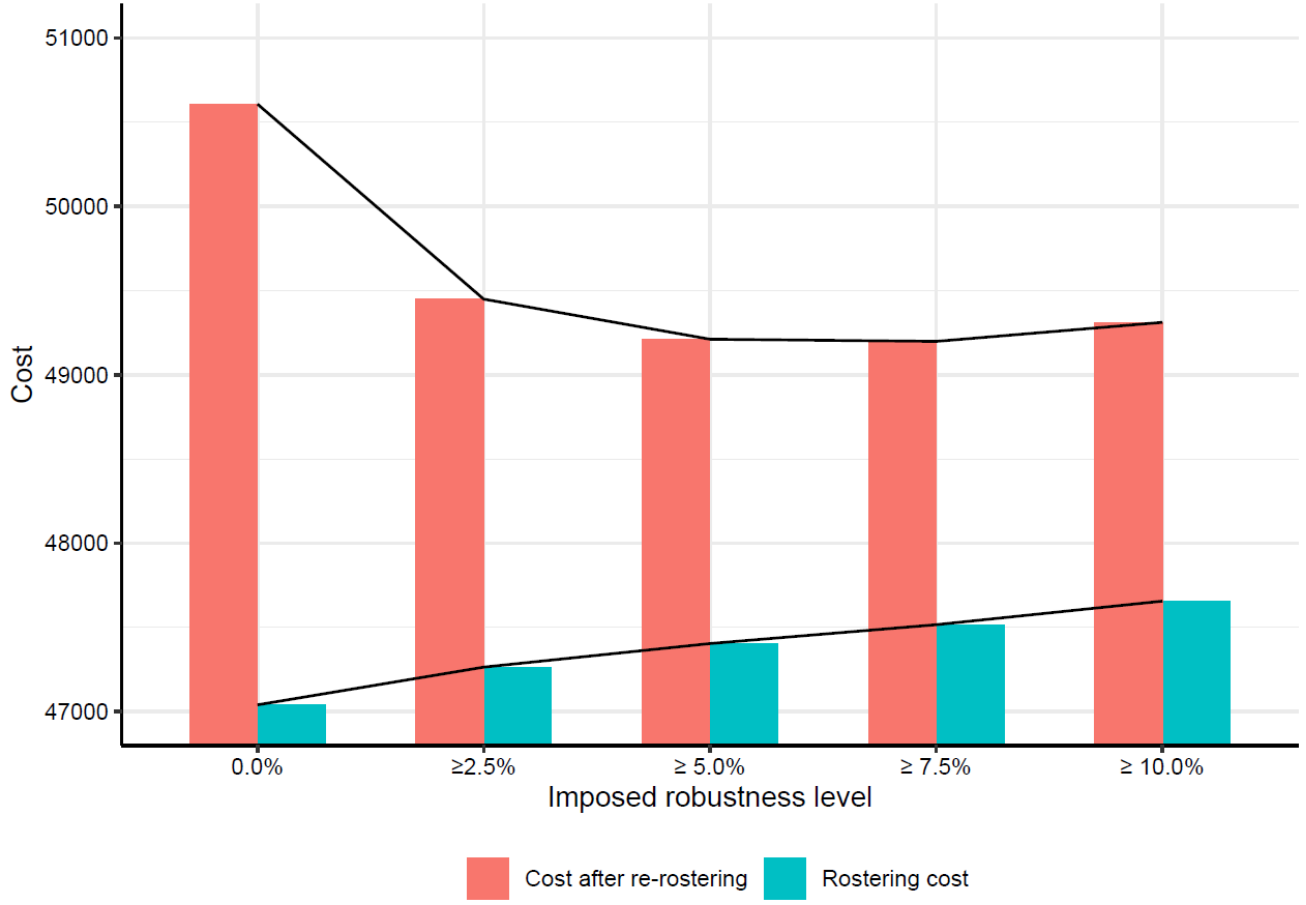
Ceschia, S., Dang, N., De Causmaecker, P., Haspeslagh, S., & Schaerf, A. (2019). The second international nurse rostering competition. Annals of Operations Research, 274(1), 171-186.

Computational study



Ingels, J., & Maenhout, B. (2015). The impact of reserve duties on the robustness of a personnel shift roster: An empirical investigation. Computers & Operations Research, 61, 153-169.

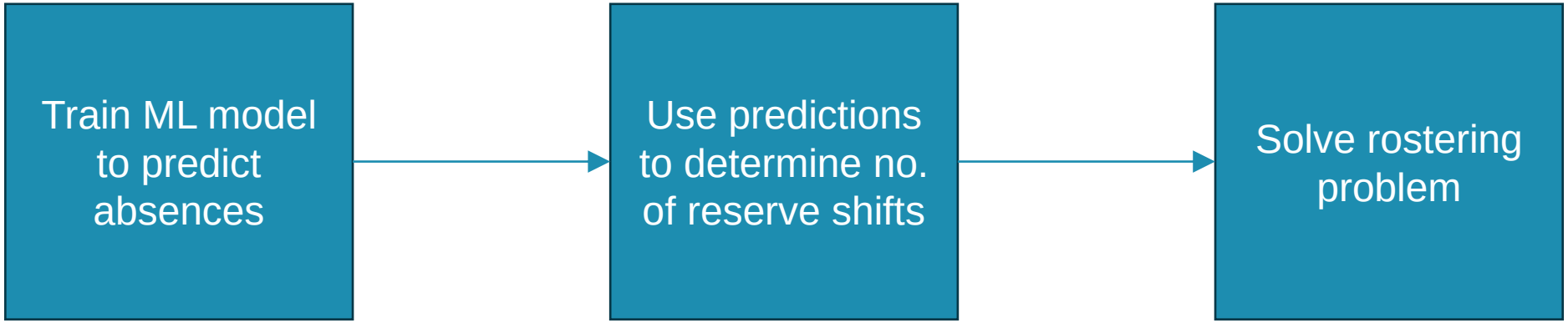
Computational study – No skills



Comparison of robustness levels and rostering cost and cost after re-rostering.

Data-driven robust rostering

- Requires human expert/experiments to determine a suitable number of reserve shifts
- Use data in a predict-then-optimize approach

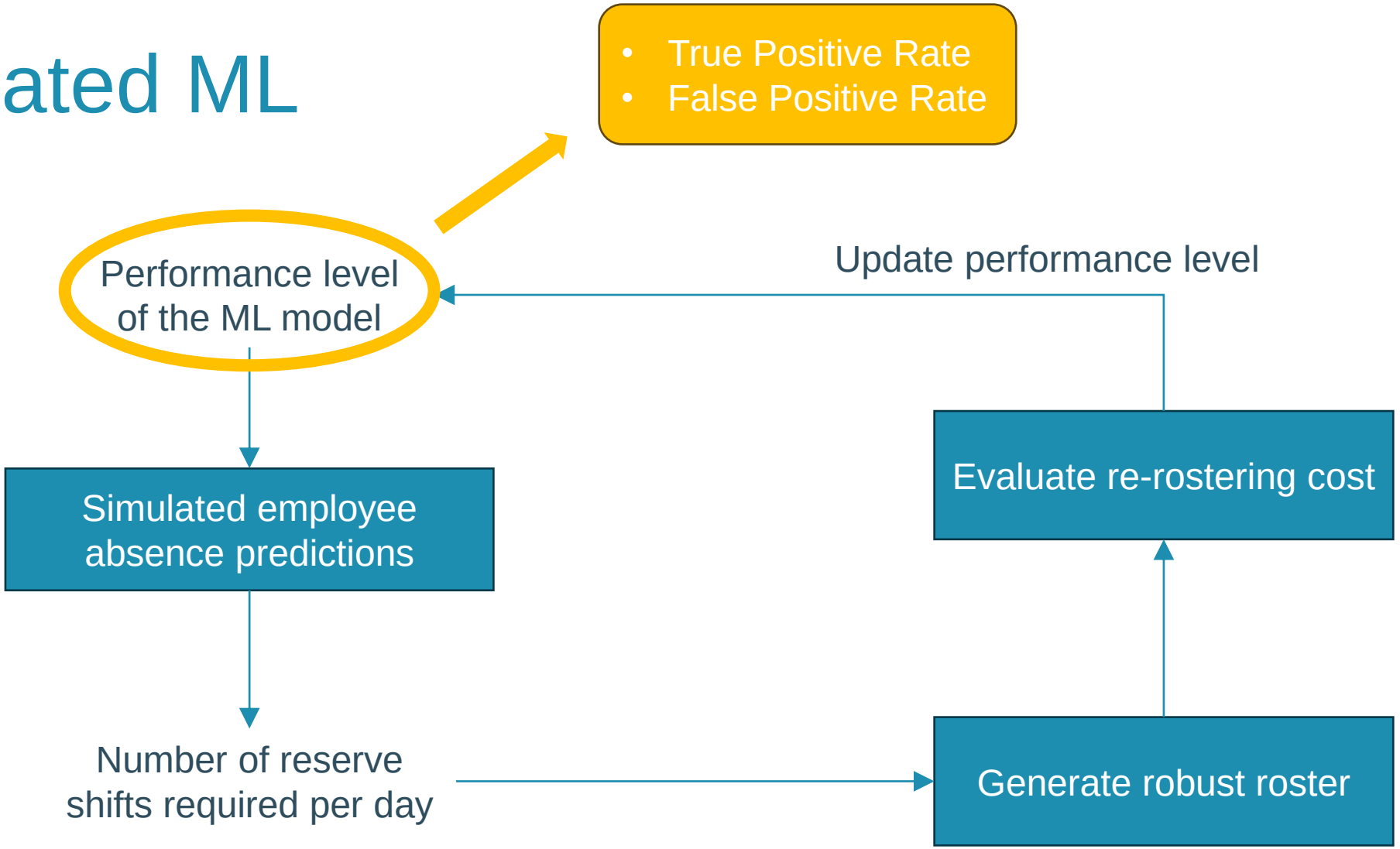


Required performance?

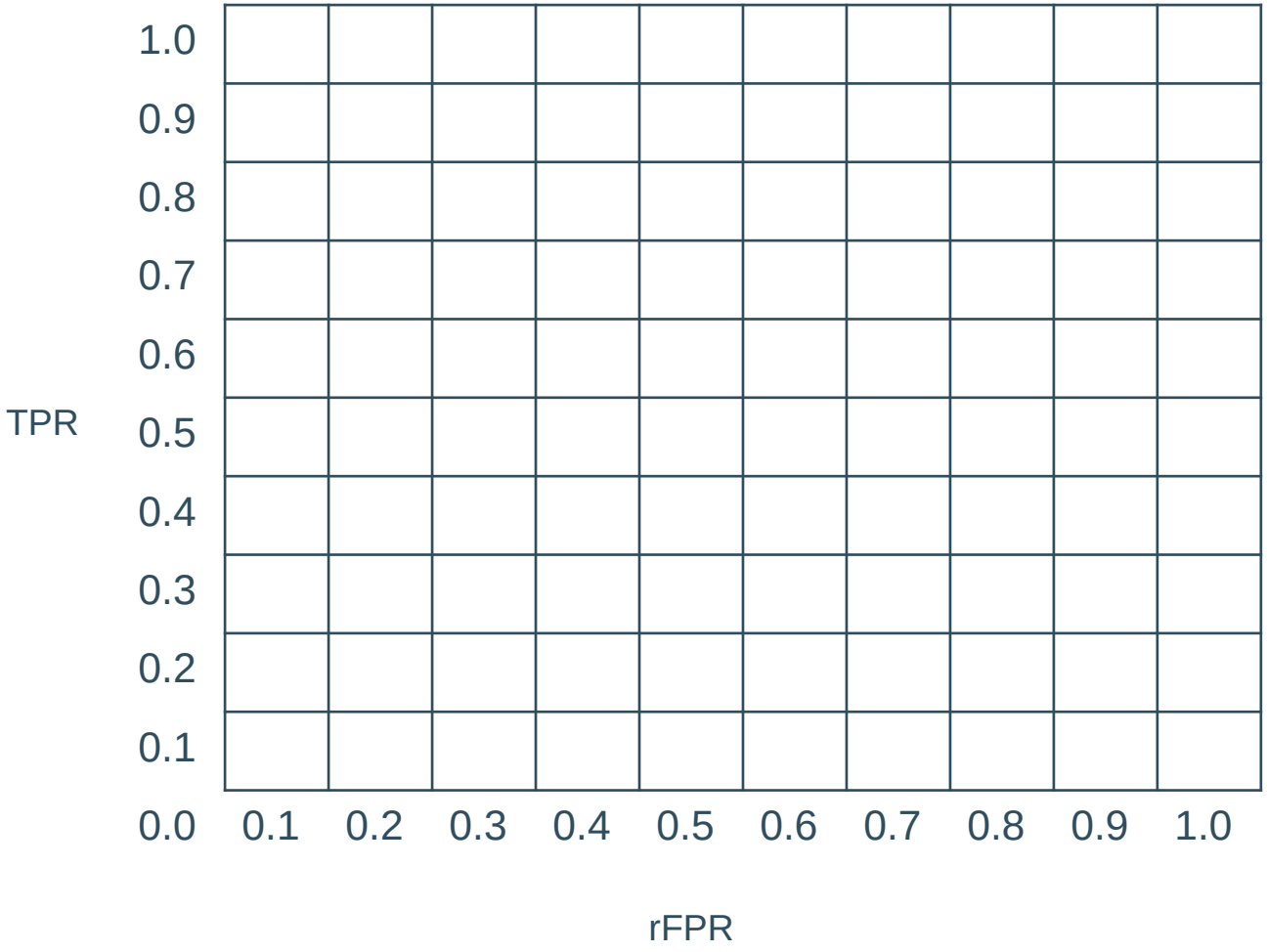
Evaluating machine learning models for data-driven robust personnel rostering

Joint work with Martina Doneda, Giuliana Carello, Ettore Lanzarone and Greet Vanden Berghe

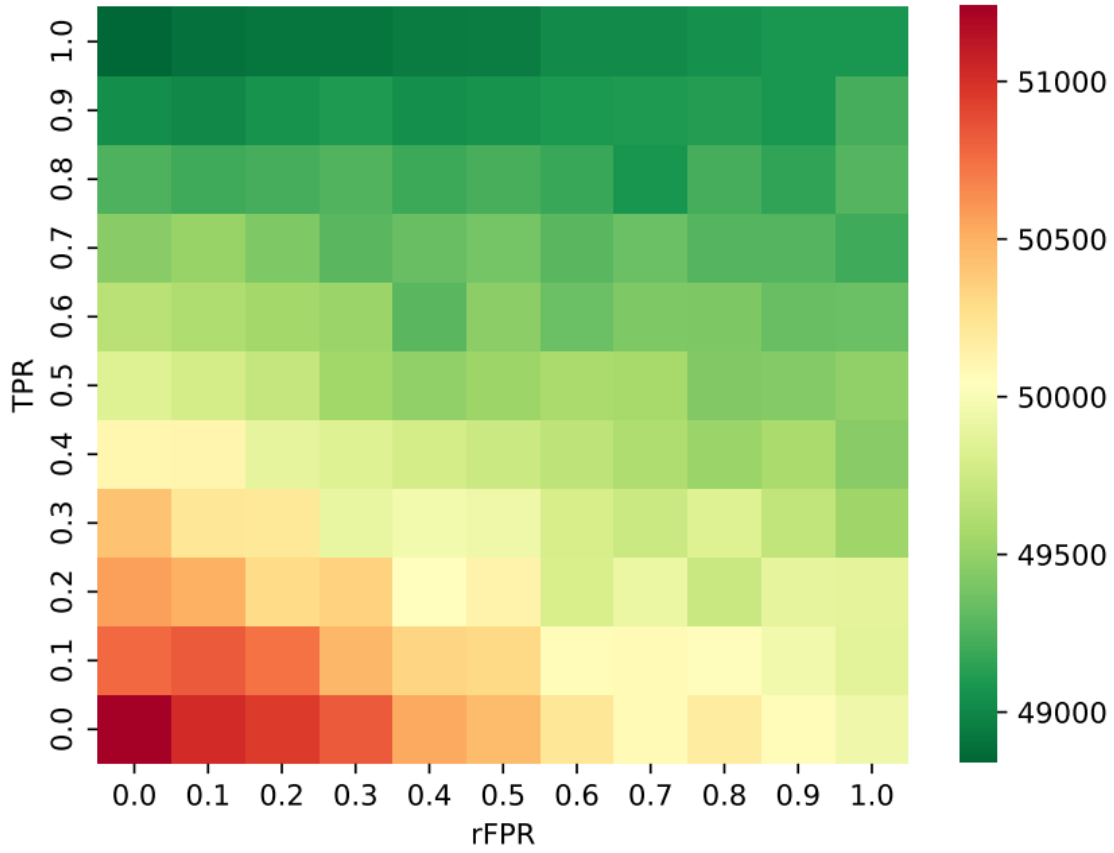
Simulated ML



Computational study

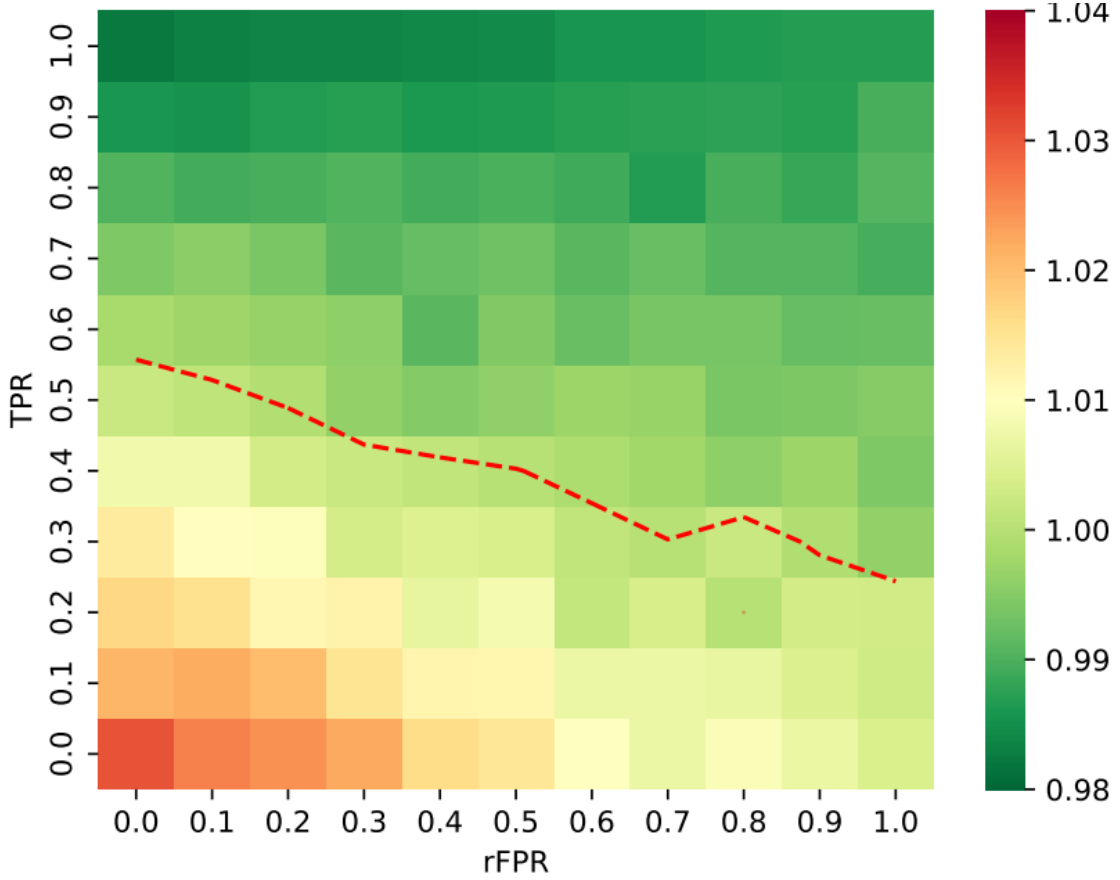


Computational study – No skills



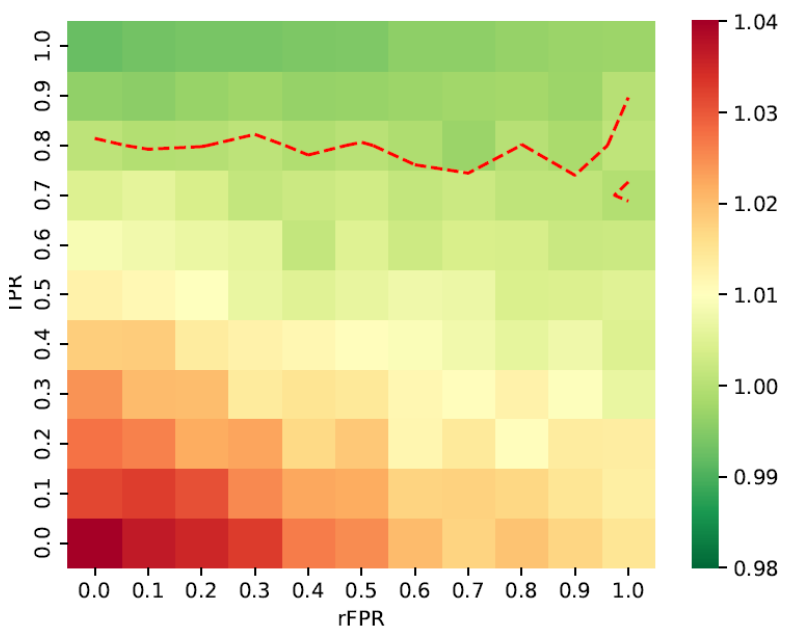
- Re-rostering cost in function of TPR and rFPR
- Lowest cost obtained when absences and non-absences are predicted correctly (TPR=1 and rFPR=0)
- In general, it is better to be conservative and to assign (too) many reserve shifts

Computational study – No skills

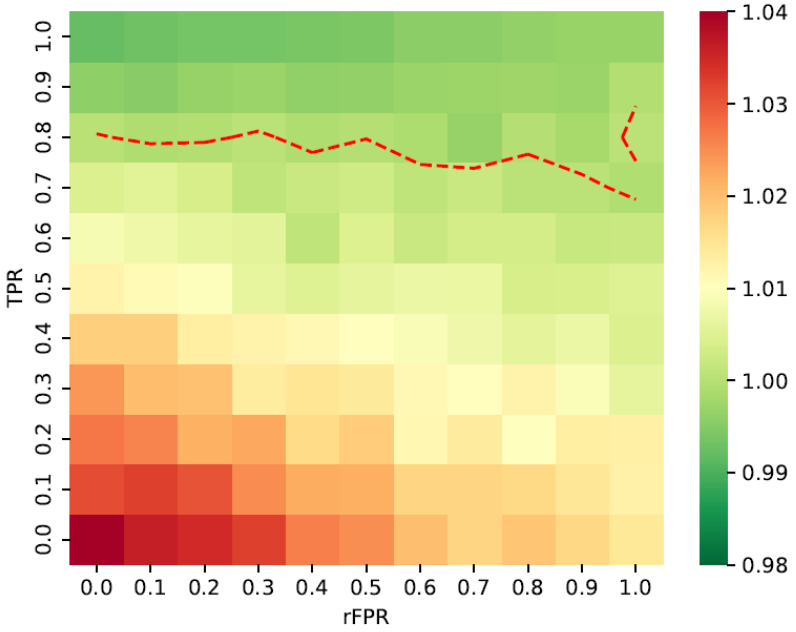


- Comparison to a non-data-driven approach that assigns 1 reserve shifts per day
- Ratio of re-rostering cost of ML-informed approach over re-rostering cost of non-data-driven approach
- ML-informed approach generates better solutions under reasonable conditions

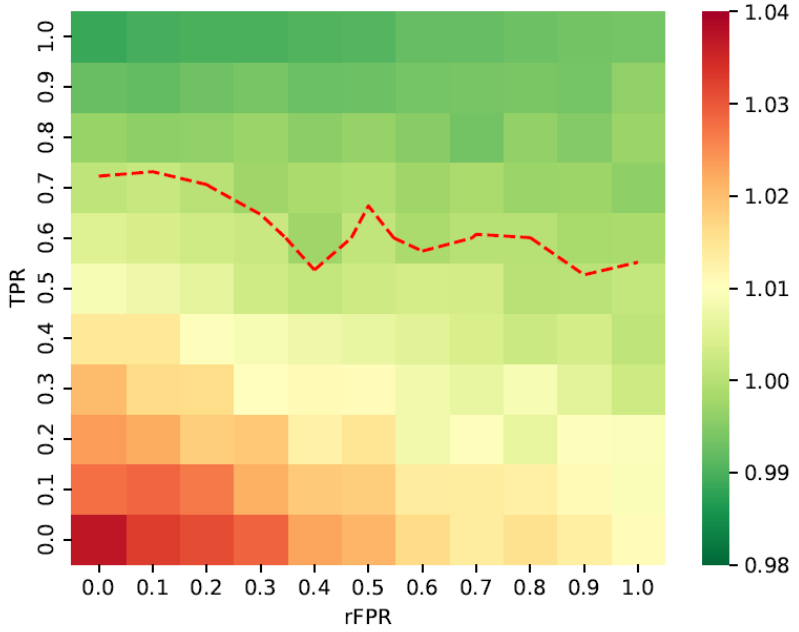
Computational study – No skills



(b) Two reserve shifts per day

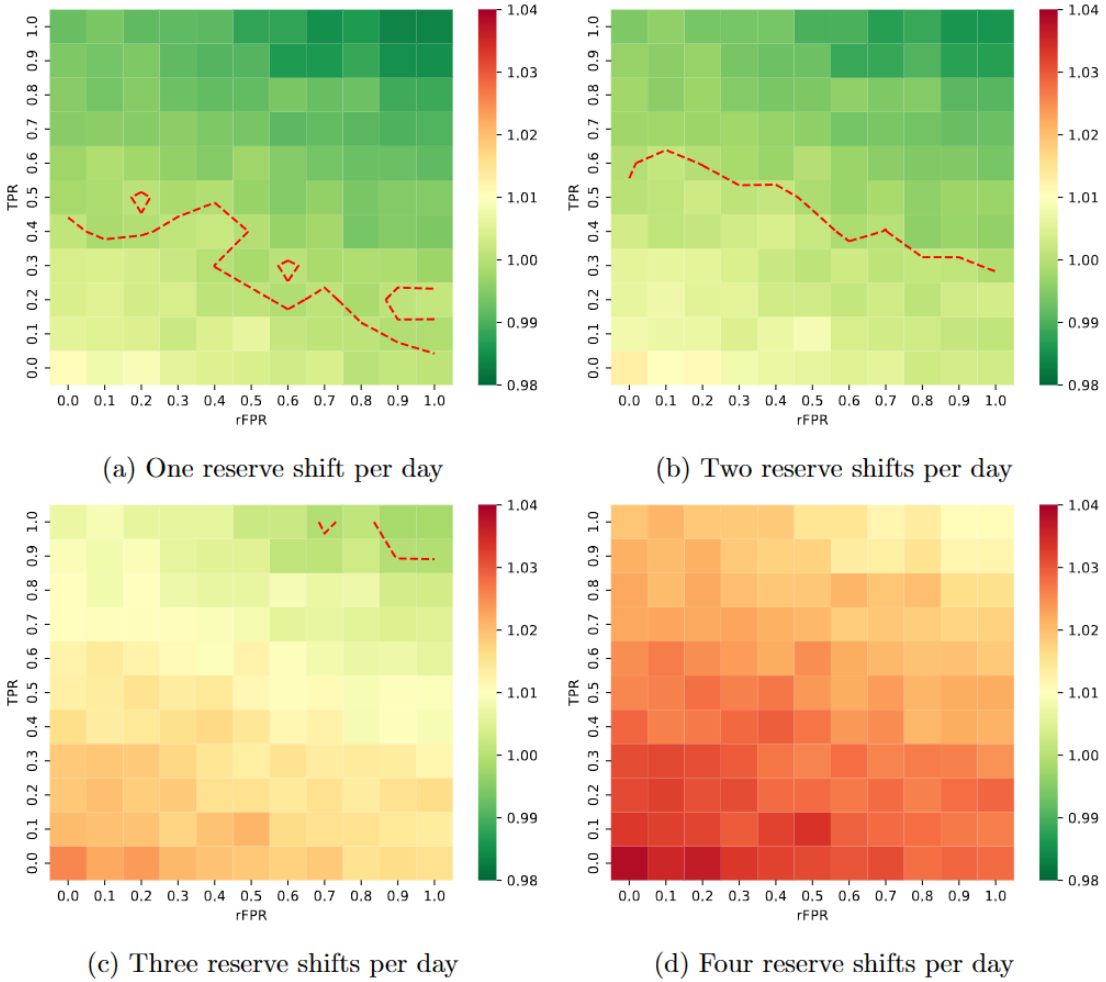


(c) Three reserve shifts per day



(d) Four reserve shifts per day

Computational study – Hierarchical skills



(a) One reserve shift per day

(b) Two reserve shifts per day

(c) Three reserve shifts per day

(d) Four reserve shifts per day

- Comparison to a non-data-driven approach that assigns 1, 2, 3 or 4 reserve shifts per day
- Ratio of re-rostering cost of ML-informed approach over re-rostering cost of non-data-driven approach
- The ML-informed approach cannot outperform the non-data-driven approach that assigns 4 reserve shifts per day

Conclusions and future research

Conclusions

- Uncertainty is always there when scheduling humans
- Proactive rostering helps mitigate negative effects of reactive rostering
- Methodology to generate robust rosters using capacity and reserve shift buffers
- Improve robustness by considering data on absenteeism
- Methodology to evaluate ML prediction performance requirements

Model the true impact of reactive rostering on employee well-being (health, job engagement,…) ?

Explore other types of roster robustness. ?

Generalize the simulated ML methodology. ?

Outlook

- Major shift after the COVID-19 pandemic
  - Increased workload (negative)
  - Increased flexibility (positive)

- Employee schedules should consider:
  - Reliability
  - Autonomy
  - Fairness

Thank you for your attention

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