Models and Algorithms for Manpower Planning and Personnel Rostering: Towards An Integrated Approach

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Promotor: Prof. dr. Marie-Anne Guerry

February 19, 2015
Research backgrounds

Over/under qualified personnel

Unattractive working schedule

Qualified personnel shortage

Ageing workforce

Personnel planning research

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Research backgrounds

Unattractive working schedule
Qualified personnel shortage
Ageing workforce
Over/under qualified personnel
Qualified personnel shortage

Research Limitation
Focus on corporate/organization
Personnel planning research

Quantitative approach

Overview of Our Work

Manpower Planning and Personnel Rostering

- Integrated model
- Three-step evaluation (Chap. 2)
- Optimization approach (Chap. 3)
- Balancing three criteria (Chap. 4)
- Stochastic Model (Chap. 5)
- Manpower planning
- Personnel Rostering
- Individual fairness (Chap. 6)
Manpower planning

- aims to meet **medium-to-long term** human resource requirements
- involves personnel supply-and-demand prediction
- controls **recruitments, personnel transition** and **wastage** (depending on the chosen strategy)

![Personnel structure](hand-drawn圩构.png)

<table>
<thead>
<tr>
<th>2015</th>
<th>90</th>
<th>30</th>
<th>65</th>
</tr>
</thead>
</table>

**Hospital**
Manpower planning

- aims to meet medium-to-long term human resource requirements
- involves personnel supply-and-demand prediction
- controls recruitment, personnel transition and wastage (depending on the chosen strategy)
Manpower planning

- aims to meet medium-to-long term human resource requirements
- involves personnel supply-and-demand prediction
- controls recruitment, personnel transition and wastage (depending on the chosen strategy)
Personnel rostering

- **short term planning** to allocate personnel into shifts
- involves coverage requirements, legal and personal constraints
- aims to meet coverage requirements and avoid unattractive rosters.

Feb. 2015
### Personnel rostering - Illustration

<table>
<thead>
<tr>
<th>Nurse</th>
<th>February 2015</th>
<th>Score</th>
</tr>
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<tbody>
<tr>
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<table>
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<table>
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<table>
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<th>Score</th>
</tr>
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<tr>
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<td>![Day Icon]</td>
</tr>
<tr>
<td>3</td>
<td>![Day Icon]</td>
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</table>

<table>
<thead>
<tr>
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<tbody>
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</tr>
<tr>
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<td>![Day Icon]</td>
<td></td>
<td></td>
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</tbody>
</table>

The table above illustrates the personnel rostering for February 2015, showing the number of days each nurse is scheduled (represented by the sun icon) and the number of days they are required to work (represented by the moon icon). The score column indicates the rating of each nurse's performance.
## Personnel rostering - Illustration

### Nurse Rostering - February 2015

<table>
<thead>
<tr>
<th>Nurse</th>
<th>February 2015</th>
<th>Score</th>
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</thead>
<tbody>
<tr>
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<td>1  2  3  4  5  6  7  ...  28</td>
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</tbody>
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Integrated model (Chaps. 2 & 3)

Manpower Planning and Personnel Rostering

- Three-step evaluation (Chap. 2)
- Optimization approach (Chap. 3)
- Manpower planning
- Balancing three criteria (Chap. 4)
- Stochastic Model (Chap. 5)
- Personnel Rostering
- Individual fairness (Chap. 6)
Challenges and Motivation

Personnel Planning

Personnel supply-demand projection

Manpower planning

Personnel rostering

Dept.1

Dept.2

Dept.3

- Conducted sequentially
- Different time frame
Challenges and Motivation

Personnel Planning

Personnel supply-demand projection

Manpower planning

Personnel rostering

Dept.1
Dept.2
Dept.3

Poor rosters

- Conducted sequentially
- Different time frame
- Potentially produce poor results

Motivation and Contribution

Integrated model (Chaps. 2 & 3)
Challenges and Motivation

Personnel Planning

- Personnel supply-demand projection
- Manpower planning
- Personnel rostering

Feedback

- Conducted sequentially
- Different time frame
- Potentially produce poor results
- Our motivation: provide feedbacks

Poor rosters

Dept.1
Dept.2
Dept.3

2015
90 30 65

2016
95 35 75

90 30 65

30 65

95 35 75

Demand
Demand
## Contributions

### The State-of-The-Art:

<table>
<thead>
<tr>
<th>No</th>
<th>Approach</th>
<th>References</th>
<th>Review</th>
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<td><strong>Sequential planning</strong></td>
<td>Abernathy et al. (1973); Ozcan (2009)</td>
<td><strong>Suboptimal solutions</strong></td>
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<tr>
<td>2</td>
<td><strong>Integrated staffing and rostering</strong></td>
<td>Mundschenk and Drexl (2007); Beliën et al. (2012)</td>
<td>Constraints are rather <strong>limited</strong>; Less personalized rosters</td>
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<tr>
<td>3</td>
<td><strong>Part-time/Annualized personnel</strong></td>
<td>Bard and Purnomo (2006); Corominas and Pastor (2010)</td>
<td>Only <strong>temporary solution</strong></td>
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<tr>
<td>4</td>
<td><strong>Staff allocation</strong></td>
<td>Haspeslagh (2012); Maenhout and Vanhoucke (2013)</td>
<td>Focus only on <strong>staff allocation</strong></td>
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Contributions

The State-of-The-Art:

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<td>Staff allocation</td>
<td>Haspeslagh (2012); Maenhout and Vanhoucke (2013)</td>
<td>Focus only on staff allocation</td>
</tr>
</tbody>
</table>

Our Contributions:

- Three-step approach for limited personnel structure modification.
- Optimization approach for arbitrary personnel structure modification.
Three-step approach (Chap. 2)

Step 1. Consistency check
- Compare the required and the available resources
- Disregard many rostering constraints
Three-step approach (Chap. 2)

Step 1. Consistency check
- Compare the required and the available resources
- Disregard many rostering constraints

Step 2. Quality evaluation of the current personnel structure
- Solve the rostering problems
- Identify which personnel group inappropriate
Three-step approach (Chap. 2)

Step 1. Consistency check
- Compare the **required** and the **available** resources
- Disregard many rostering constraints

Step 2. Quality evaluation of the current personnel structure
- Solve the rostering problems
- Identify **which personnel group** inappropriate

Step 3. Quality evaluation of the neighboring personnel structures
- **Small modification** to the personnel structure
- Evaluate the roster qualities
Response surface meth. (RSM)

- **Sampling** the neighborhood of the current solution
- Perform **regression analysis** to find new direction
Response surface method (RSM)
- **Sampling** the neighborhood of the current solution
- Perform **regression analysis** to find new direction

Simulated Annealing (SA)
- **Local search** to generate neighboring solutions
- Move to the best neighboring solution with a certain probability

Diagram:
- Initial solution → Neighborhood sampling → Regression
- Initial solution → Local search → Accept with SA criteria
- Current solution → Local search → Accept with SA criteria
Case studies

- The data set originating from real-world nurse rostering problems is taken from Bilgin et al. (2012).
- The three-step approach is provided for the Emergency ward only.

<table>
<thead>
<tr>
<th>No</th>
<th>Ward</th>
<th>Abbr.</th>
<th>k</th>
<th>( \sum FTE )</th>
<th>( \bar{q}v_{T_0^s, T_1^s}(R(n)) )</th>
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</thead>
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<tr>
<td>1</td>
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<td>Em</td>
<td>8</td>
<td>26.25</td>
<td>17,309</td>
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<tr>
<td>2</td>
<td>Geriatrics</td>
<td>Gr</td>
<td>8</td>
<td>17.06</td>
<td>11,423</td>
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<tr>
<td>3</td>
<td>Meal Preparations</td>
<td>MP</td>
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<td>16.84</td>
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<td>13.75</td>
<td>14,447</td>
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<td>6</td>
<td>Palliative Care</td>
<td>PC</td>
<td>20</td>
<td>21.70</td>
<td>130,579</td>
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</tbody>
</table>

- \( k \): Number of subgroups
- \( \sum FTE \): The current total of full time equivalent in the ward
- \( \bar{q}v_{T_0^s, T_1^s}(R(n)) \): The value of the roster quality (the smaller the better)
Case study results (three-step approach)

### Step 1. Consistency check

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio</td>
<td>0.95</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
</tr>
</tbody>
</table>

### Step 2. Quality evaluation of the current personnel structure

- **Coverage constraint:**
  - Skill type 1: 1.6%
  - Skill type 3: 2.2%
  - Skill type 4: 80.1%

- **Counter constraint:** 10.2%

- **Series constraint:** 2.9%

**Ratio** = \(\frac{\text{Required resources}}{\text{Available resources}}\)
Case study results (three-step approach)

Step 1. Consistency check

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Ratio</th>
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<tbody>
<tr>
<td>1</td>
<td>0.95</td>
</tr>
<tr>
<td>2</td>
<td>0.85</td>
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<tr>
<td>3</td>
<td>0.85</td>
</tr>
<tr>
<td>4</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Ratio = \frac{\text{Required resources}}{\text{Available resources}}

Reasonable, some slack for vacation/illness

Step 2. Quality evaluation of the current personnel structure

Coverage constraint:
Skill type 1: 1.6%
Skill type 3: 2.2%
Skill type 4: 80.1%

Counter constraint: 10.2%
Series constraint: 2.9%

Proportion of the total weighted constraint violations

Skill 4 understaffed
Step 3. Quality evaluation of the neighboring personnel structures

Increase the number of nurses with skill type 2, 3 or 4.

(a) subgroup of primary skill type 1

(b) subgroup of primary skill type 2

(c) subgroup of primary skill type 3

(d) subgroup of primary skill type 4
## Optimization approach (RSM & SA)

<table>
<thead>
<tr>
<th>No</th>
<th>Ward</th>
<th>( \sum FTE )</th>
<th>RSM ( \tilde{q}v_{T_0^i, T_1^i}(R(n)) )</th>
<th>ratio</th>
<th>( \sum \tilde{FTE} )</th>
<th>SA ( \tilde{q}v_{T_0^i, T_1^i}(R(n)) )</th>
<th>ratio</th>
<th>( \sum \tilde{FTE} )</th>
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<tr>
<td>1</td>
<td>Em</td>
<td>26.25</td>
<td>13,176</td>
<td>76.13%</td>
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<td>76.85%</td>
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<td>4,508</td>
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<td>MP</td>
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<td>Ps</td>
<td>16.50</td>
<td>5,182</td>
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<td>4,060</td>
<td>46.49%</td>
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<td>5</td>
<td>Re</td>
<td>13.75</td>
<td>9,750</td>
<td>67.49%</td>
<td>14.65</td>
<td>10,212</td>
<td>70.69%</td>
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<td>6</td>
<td>PC</td>
<td>21.70</td>
<td>50,583</td>
<td>38.74%</td>
<td>17.42</td>
<td>20,111</td>
<td>15.40%</td>
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</table>

- Small modification on the total FTE can lead to a better roster quality
- SA performs slightly better
Overview Chapters 4 & 5

Manpower Planning and Personnel Rostering

- Integrated model
  - Three-step evaluation (Chap. 2)
  - Optimization approach (Chap. 3)
- Manpower planning
  - Balancing three criteria (Chap. 4)
  - Stochastic Model (Chap. 5)
- Personnel Rostering
  - individual fairness (Chap. 6)
Challenge and motivations

- What if the desired personnel structure is difficult to reach?
- How we ensure that the promotion policy does not harm the personnel motivation?
- How we deal with uncertainties?

Motivation: develop models and algorithms for manpower planning problems
Contributions

The State-of-The-Art:

- The degree of desirability and the degree of attainability have been introduced in Guerry (1999); De Feyter and Guerry (2009)
- Previous approaches use an unrestricted promotion strategy that can lead to personnel dissatisfaction (Song and Huang, 2008; Nilakantan et al., 2011)
- No method has been proposed to find the most beneficial manpower planning policy with stochastic wastage (Davies, 1982; Guerry, 1993)
Contributions

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- No method has been proposed to find the most beneficial manpower planning policy with stochastic wastage (Davies, 1982; Guerry, 1993)

Our contributions

- Introduce MIP models for manpower planning problems that include the promotion steadiness degree (Chap. 4 & 5)
- Introduce a stochastic optimization problem and its complexity analysis to deal with wastage uncertainties (Chap. 5)
Manpower planning with three criteria (Chap. 4)

Optimizing three criteria

- The degree of attainability
  \[
  \alpha_{n_i(t)}(s_i) = \begin{cases} 
  0, & \text{if } s_i < s_{LL,i} \text{ or } s_i > s_{UL,i} \\
  \frac{s_i - s_{LL,i}}{n_i(t) - s_{LL,i}}, & \text{if } s_{LL,i} \leq s_i \leq n_i(t) \\
  \frac{s_i - s_{UL,i}}{n_i(t) - s_{UL,i}}, & \text{if } n_i(t) \leq s_i \leq s_{UL,i} 
  \end{cases}
  \]

- The degree of desirability \( \beta_i(n_i(t)) \)

- The degree of promotion steadiness \( \gamma_{ij}(\bar{f}_{ij}(t - 1, t)) \)

---

Difference between \( n(t) \) and the attainable set

Difference between \( n(t) \) and the desired personnel structure

Difference between the personnel transition and the 'common' promotion policy
The model of Chap. 4

Optimizing three criteria

- Mixed integer nonlinear program (MINLP)
- Piecewise linear approximation (PLA) to handle nonlinearity
- The model is solved using an iterated PLA
The model of Chap. 4

Optimizing three criteria

- Mixed integer nonlinear program (MINLP)
- Piecewise linear approximation (PLA) to handle nonlinearity
- The model is solved using an iterated PLA

Set lower & upper bounds
Increase # segments
Solve PLA model
Low accuracy?
Yes
# Experiments for model of Chap. 4

<table>
<thead>
<tr>
<th>No</th>
<th>Problem</th>
<th>( k )</th>
<th>( \kappa )</th>
<th>(^a)Comp. time</th>
<th>( \kappa )</th>
<th>(^a)Comp. time</th>
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<td>P30</td>
<td>30</td>
<td></td>
<td></td>
<td>(^c)0.184</td>
<td>2.74</td>
</tr>
</tbody>
</table>

\(^a\)In seconds
\(^b\)Solver is terminated after 1 hour
\(^c\)Solver terminates: out of memory without encountering a feasible solution

- \( \kappa \): the overall objective function value
- with similar value of \( \kappa \), IPLA model is more efficient than the PLA
Optimizing partially stochastic system

- The degree of desirability
- The degree of promotion steadiness
- **wastage is considered stochastic**, following a probability distribution

Difference between $n(t)$ and the desired personnel structure

Difference between the personnel transition and the 'common' promotion policy
Partially stochastic system

- The stochastic wastage is modeled using a finite number of scenarios.
- The MIP model is solved using a MIP solver.
- The problem is proved to be NP-hard based on reduction from 3-SAT.

Case study with 3 subgroups

- Using the deterministic case \( w = \bar{w} \), then the result is tested under stochastic case \( w \), the overall degree \( \bar{\kappa} = 0.78099 \).
- Using the stochastic case \( w_i \) with 1000 scenarios, the overall degree \( \bar{\kappa} = 0.8019 \).
Overview Chapter 6

Manpower Planning and Personnel Rostering

- Integrated model
  - Three-step evaluation (Chap. 2)
  - Optimization approach (Chap. 3)
  - Manpower planning
    - Balancing three criteria (Chap. 4)
    - Stochastic Model (Chap. 5)

- Personnel Rostering
  - individual fairness (Chap. 6)
### Challenges and Motivation

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(BUTO) Integrated Manpower Planning & Personnel Rostering
## Challenges and Motivation

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**Low individual fairness**

**Motivation:**
incorporate fairness in personnel rostering model
## Contributions

### The State-of-The-Art:

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Our Contribution is the lexicographic objective function:
- Minimize all individual penalties
- maximize fairness by allowing positive trade-off.
Improving fairness

Minimizing the lexicographic objective function

- $P^{Lexi}$ is defined as a permutation of all individual penalties, sorted in a non-increasing order.

$$P^{Lexi} = (P'_{H,1}, P'_{H,2}, \ldots, P'_{H,n}) \text{ s.t. } P'_{H,1} \geq P'_{H,2} \geq \ldots \geq P'_{H,n}$$
Experiments for lexicographic objective function

- $TP-P^{Lexi}$ generally produces vectors $P^{Lexi}$ that are lexicographically smaller than the ones produced by other approaches.
Conclusions

- The models and algorithms presented are able to improve the personnel planning process
- The models and algorithms are beneficial in improving the personnel motivation by:
  - Providing sufficient personnel with the right personnel-mix (Integrated model)
  - Ensuring the career progression expectation (manpower planning model)
  - Fair working schedule (personnel rostering model)

Future research

- multi-level and multi-scale integrated personnel planning
- global optimization approach
Thank you for your attention!


References II


