Clustering Clinical Departments to Optimize Bed Occupancy Levels

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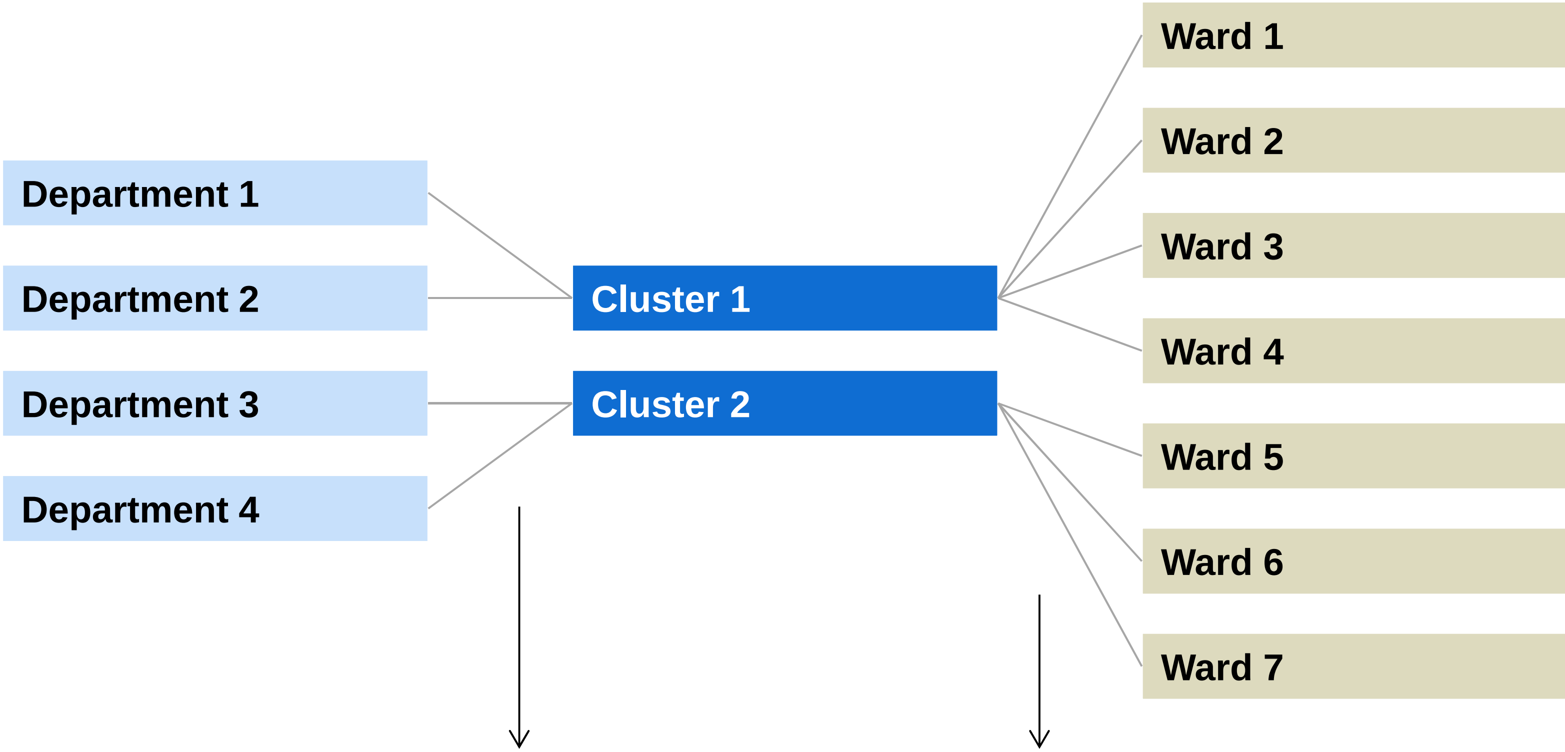
Manuel Walther
Alexander Hübner
Heinrich Kuhn

Department of Operations
Katholische Universität, Eichstätt-Ingolstadt
Auf der Schanz 49, 85049 Ingolstadt, Germany

Agenda

This model combines departments to clusters while minimizing costs for beds and personnel and keeping a predetermined service level



Departments are clustered to minimize

- Cost/Number of required beds
  while maintaining a given service level
- Additional personnel cost for clustering
  (management and training)

Wards are assigned to clusters to ensure

- Required amount of beds
  for each cluster
- Correct placement and size of clusters
  within the hospital

When clustering departments, we are focusing on a strategical problem

Overview of typical clinical planning problems

☐ Focus of this document — SIMPLIFIED, NOT EXHAUSTIVE

Hospital Resource Management

Planning Horizon	Operating Rooms	Personnel Placement	Bed Occupancy	Support Functions[1]
Strategical (months – years)	▪ Sizing of OR-infrastructure ▪ Location planning	▪ Long-term personnel capacity planning (recruiting, hiring, professional development)	▪ Clustering of clinical departments ▪ Allocation of ward space to clusters	▪ Long-term capacity planning ▪ Location planning
Tactical (weeks – months)	▪ Master surgery schedule planning (incl. emergency buffers)	▪ Rolling planning of personnel placement based on anticipated workload	▪ Process planning for bed occupancy (e.g., admission and demission time)	▪ Cyclic usage schedule planning ▪ Consumable planning
Operational (days – weeks)	▪ Ad-hoc OR-scheduling (daily adjustment to meet emergencies and cushion constraints)	▪ Ad-hoc reshuffling of personnel to meet short-term workload developments	▪ Ad-hoc occupancy planning ▪ Appointment planning for elective patients	▪ Daily allocation planning of resources to departments (e.g., via time slots)

When devising optimization models for these problems, it is important to understand interdependencies and model possible constraints accordingly

1 E.g., Radiology, medical laboratories, ...

Source: Table freely adapted from Hulshof et al. (2012 – Health Systems)

Agenda

1 Motivation

2 **Literature Overview / Problem Context**

3 Proposed Model

4 First Results and Next Steps

An initial literature review has revealed some gaps for the department clustering problem that we would like to address

Focus for new modeling approach

Overview of existing approaches
(selection)

- **„Clustering Clinical Departments for Wards to Achieve a Prespecified Blocking Probability"** – Van Essen et al. (2015 – OR Spectrum)
- **„A hierarchical facility layout planning approach for large and complex hospitals"** – Helber et al. (2014 – Working Paper)
- **„Dimensioning hospital wards using the Erlang loss model"** – A.M.de Bruin et al. (2010 – Annals of Operations Research)
- **"A simple method to optimize hospital beds capacity"** – Nguyen et al. (2005 – International Journal of Medical Informatics)
- **„A queueing model for bed-occupancy management and planning of hospitals"** – Gorunescu et al. (2002 – Journal of the Operational Research Society)

Potential extensions

- Incorporate seasonality effects
- Consider department specific personnel constraints in clustering model
- Consider operating room constraints

One of the main gaps we want to address in our model is the inclusion of non-resolvable seasonal effects

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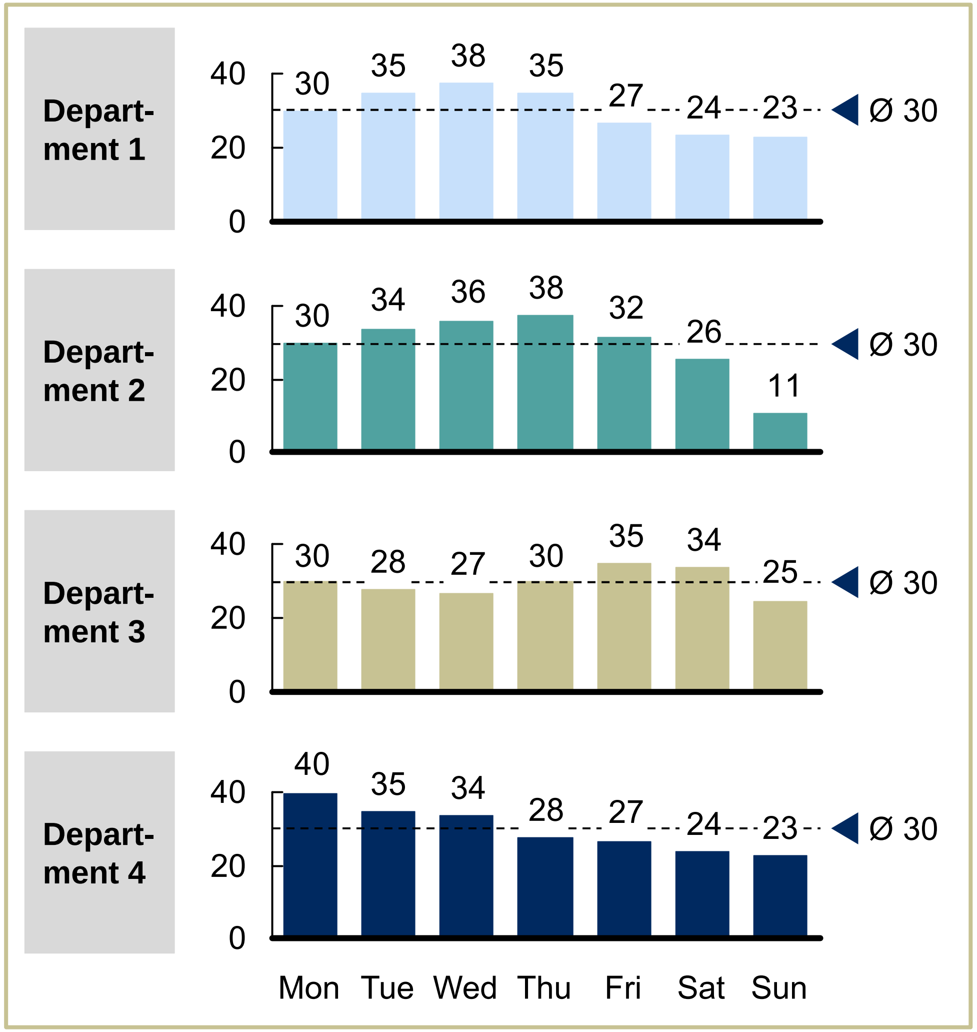
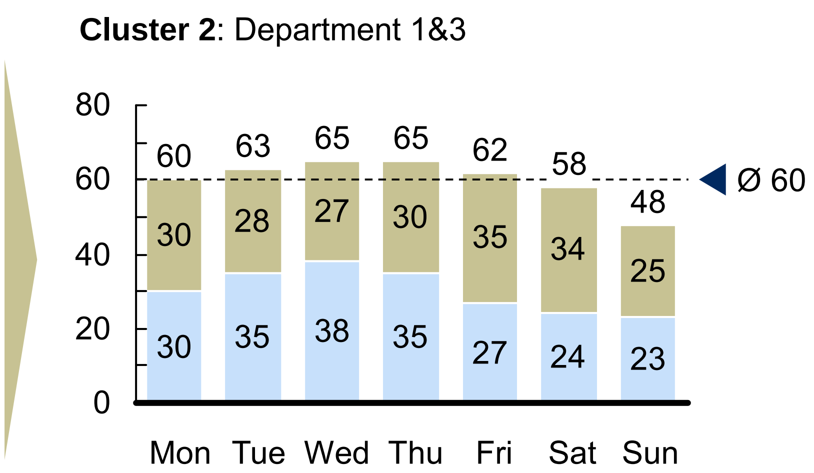
Average Number of occupied beds during a week





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Well-aligned operating room scheduling would allow to level bed occupancy by rearranging elective arrivals, but …

- Problematic/unfeasible in light of real (e.g., working hours, OR capacities, …)
- Also depends on the split between elective and non-controllable patient arrivals

Generally speaking, there are 4 important aspects that need to be considered when clustering departments and allocating ward space

Overview of relevant aspects with examples (selection only)

Medical and patient compatibility

- **Risks of infection** (e.g., avoid combining infectious and immunocomprimised patients)
- **Societal and emotional friction** (e.g., avoid combining terminally ill dementia patients with young orthopedic patients)
- **Age and gender differences** (e.g., avoid combining obstetric ward with general surgery; avoid combining children and adults)

Personnel qualification and complexity management

- **Qualification of nursing staff** (nurses are the first contact for patients and need to be able to handle all patient types of their respective cluster)
- **Operational bed management** (ensuring smooth operational processes for multiple wards requires complex management of bed allocation to avoid double-booking and shortages)

Occupancy level effects

- **Elective vs. emergency arrivals** (elective patient arrivals are less stochastic and more subject to OR-schedules, personnel planning)
- **Unique patient clientele per department** (patients exhibit different means and variances in individual length of stays resulting in varying weekly occupancy development for each department)
- **Seasonal changes** (e.g., reduction of elective surgeries in the orthopedics department during the summer)

Allocation of ward space

- **Sufficient ward space per cluster** (ward space needs to be large enough to ensure a given service level)
- **Ward position and equipment** (patients need to be close to relevant infrastructure, e.g., cardiac catheter OR for cardiology patients)
- **Cluster size** (to avoid “scattered” clusters and reduce time for rounds cluster dimensions need to be confined)

Agenda

Proposition of a new model formulation using set partitioning

Objective function		Description
(1)	$\min \sum_{c \in C} \varphi_c X_c$	Minimize cost of beds as well as cost of personnel for add. "cluster"-work
s.t.		
(2)	$\sum_{c \in C} Q_{cd} X_c = 1 \quad \forall\, d \in D$	Set Partitioning: Connection of clinical departments to clusters ("each department to one cluster")
(3)	$Y_{cw} \leq X_c \quad \forall\, c \in C; \quad \forall\, w \in W$	Connection of each ward to one "open" cluster
(4)	$\sum_{c \in C} Y_{cw} \leq 1 \quad \forall\, w \in W$	Cluster : Ward → 1 : n Each ward can only be allocated to one cluster (no allocation possible)
(5)	$Z_{wv} \geq Y_{cw} + Y_{cv} - 1 \quad \forall\, c \in C; \ \forall\, w, v \in W$	Connection of multiple wards within one cluster
(6)	$r_{wv} Z_{wv} \leq \tilde{r} \quad \forall\, w, v \in W$	Threshold for spatial cluster size
(7)	$h_{cw} Y_{cw} \leq \tilde{h}_c \quad \forall\, c \in C; \quad \forall\, w \in W$	Threshold for max. distance to fixed facilities
(8)	$X_c b_c \leq \sum_{w \in W} Y_{cw} a_w \quad \forall\, c \in C$	Meet bed requirements when assigning wards to clusters

Decision variables (binary)

X_c	$X_c = 1$ if cluster c is selected; $X_c = 0$ otherwise
Y_{cw}	$Y_{cw} = 1$ if combination cluster c and ward w is selected; $Y_{cw} = 0$ otherwise
Z_{wv}	$Z_{wv} = 1$ if wards w and v are allowed to be assigned to any one cluster; $Z_{wv} = 0$ otherwise

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$w, v \in W$	wards in hospital
$c \in C$	possible clusters (department combinations)
$d \in D$	departments in hospital

Parameters (attained during preprocessing)

φ_c	Accumulated cost per cluster including cost of required beds to ensure a given service level as well as additional personnel qualification and management cost for additional "cluster"-work
Q_{cd}	Matrix to initialize set partitioning problem; $Q_{cd} = 1$ if department d is assigned to cluster c; $Q_{cd} = 0$ otherwise
a_w	available beds per ward
b_c	beds required per cluster to meet predefined blocking probability
r_{wv}	distance between wards w and v
$\tilde{r}$	threshold; maximum allowed distance between any two wards within any one cluster
h_{cw}	distance between ward w and relevant fixed facilities (e.g. OR) for cluster c
$\tilde{h}_c$	threshold; maximum allowed distance between any ward of any one cluster to its clusters' fixed facilities

Agenda

Our approach contributes to current literature on 3 important points

	Challenge	Contribution of our approach
Seasonality effects	▪ Daily occupancy levels vary strongly between departments when looking at real-life data → Leveling occupancy prior to clustering is often impossible (Personnel constraints, accumulation of patient types, OR-schedules, …)	Seasonality effects can be modeled for any cyclic time period, e.g., weekly, monthly, and seasonal
Individual properties/ constraints per cluster	▪ The goodness of fit between potential department combinations varies strongly in real life → Simple and generalized approaches to cluster size, combination, or location do not apply	Cluster- and department-specific constraints can be set individually
Runtime and solution quality	▪ Clustering departments and assigning them to wards is a complex process with many input parameters → A time- and resource-efficient model is needed to evaluate scenarios in reasonable time	The separation of key calculations into preprocessing and mixed integer model allows for ▪ quick and optimal solutions ▪ scalability to very large hospital setups while keeping low runtimes

Further numerical examples are currently work-in-progress to demonstrate contribution

Ideas for further research

Further areas of research

- Investigate effect of **annual seasonality**
- Investigate **influence of operation room planning** approaches to clustering model
- **Combine** clustering approach **with occupancy management**
- …

Thank you for your attention

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