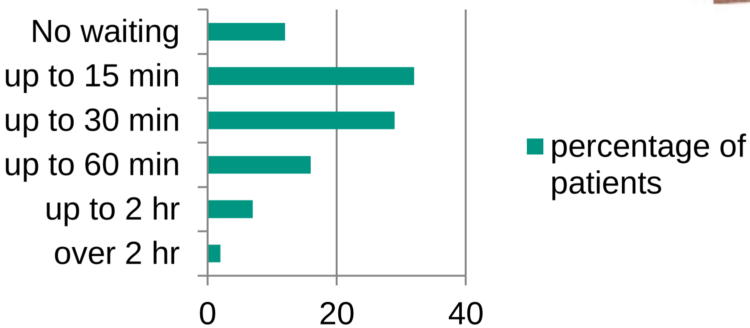
Health Care Logistics

Health Care Logistics

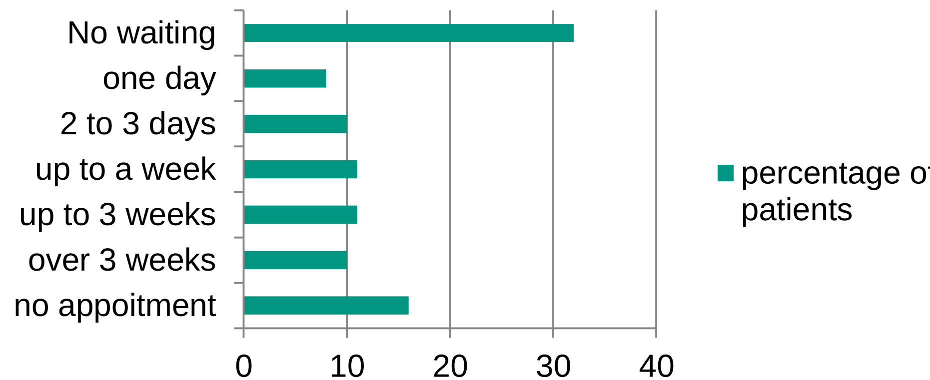
Appointment planning

Health Care Logistics

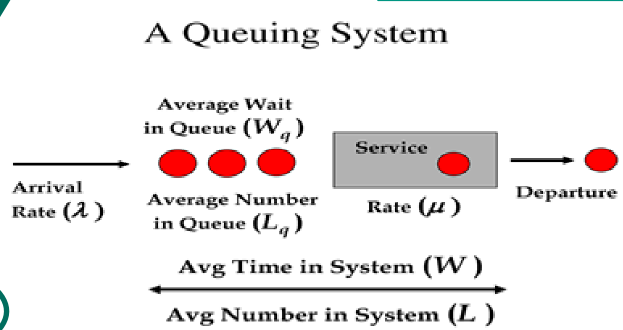
Waiting time in the practice



Waiting time for an appointment



Appointment planning



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Stefan Nickel

Process Improvement in Hospitals: A Case Study in a Radiology Department
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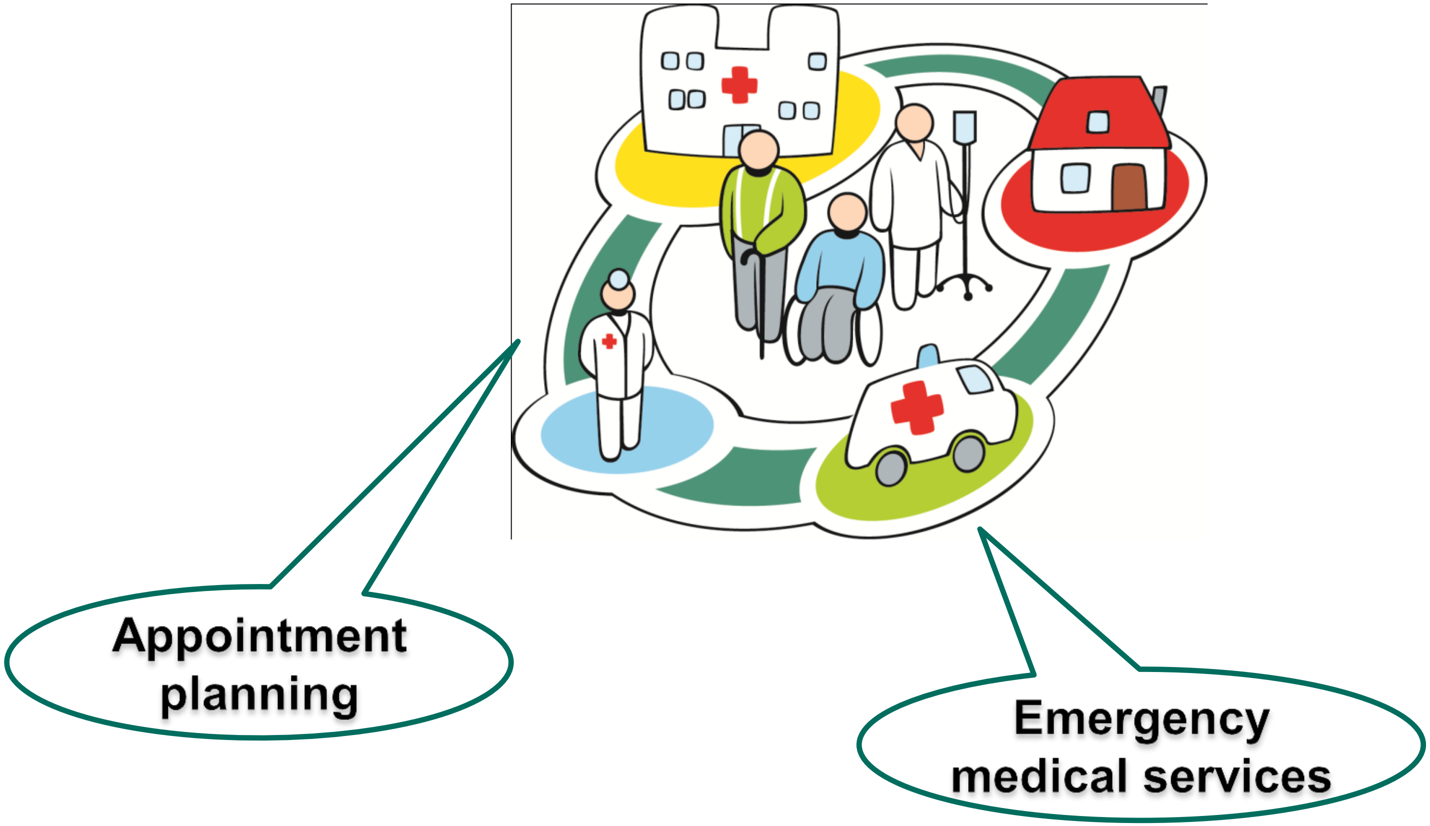
Anne Zander

Development of efficient Appointments Systemes

Data from the “Versichertenbefragung der Kassenärztlichen Bundesvereinigung 2013”

Health Care Logistics



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Melanie Reuter

Reuter, M., van Essen, T., Hurink, J. Nickel, S., "Comparing Models for Ambulance Planning on the Strategic and Tactical Level", INFORMS Healthcare 2013, Chicago, USA.

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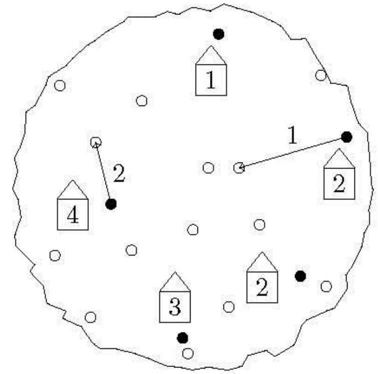
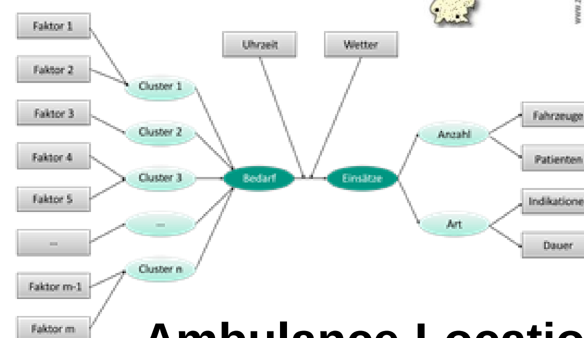
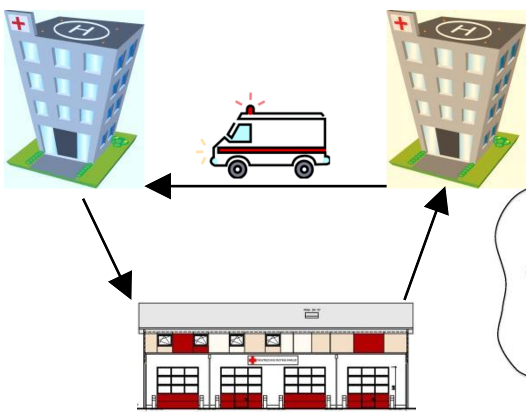
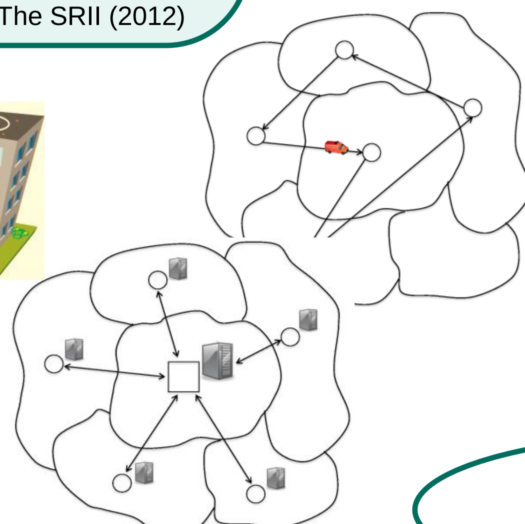






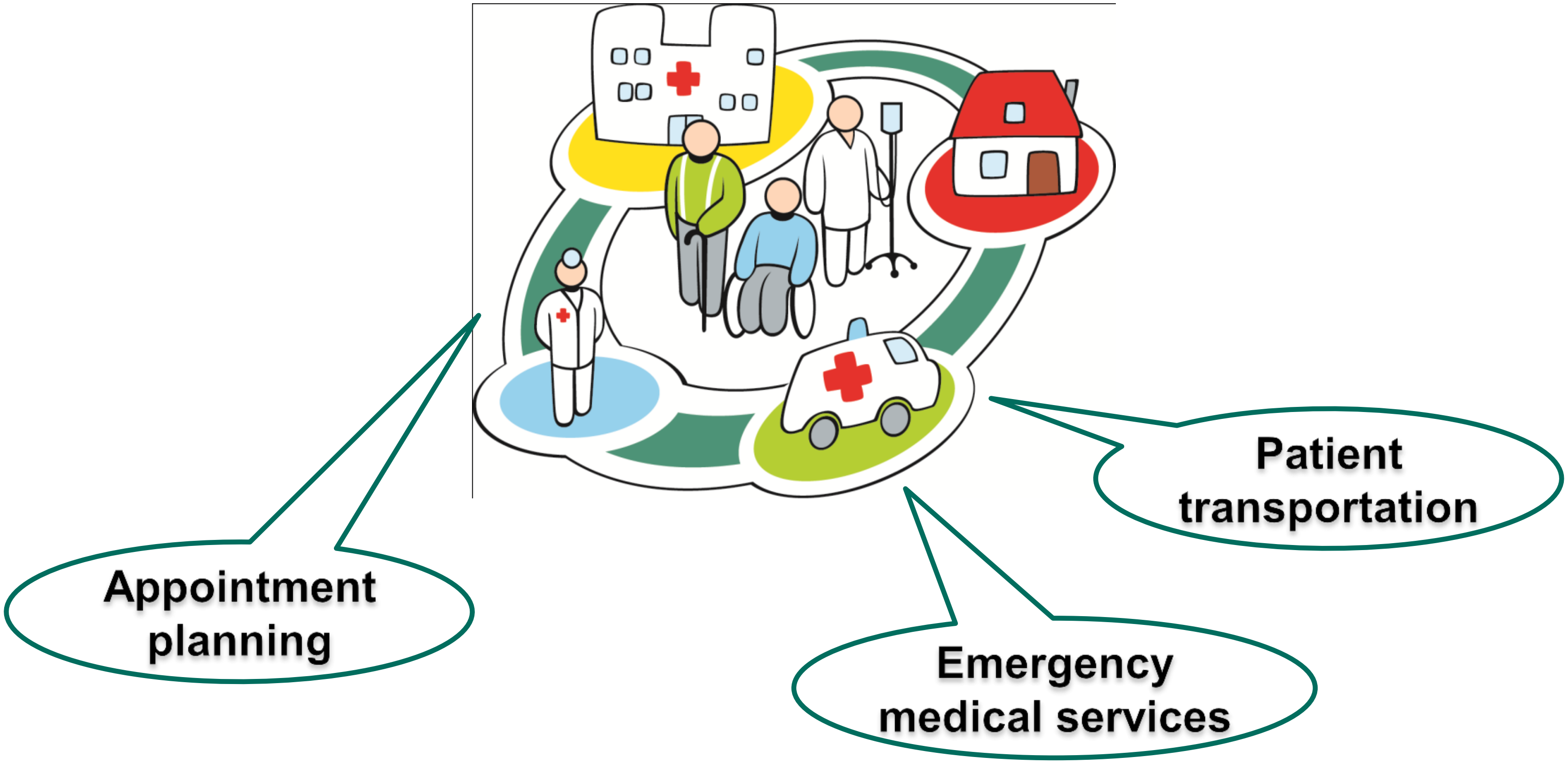


Ambulance Location and Relocation

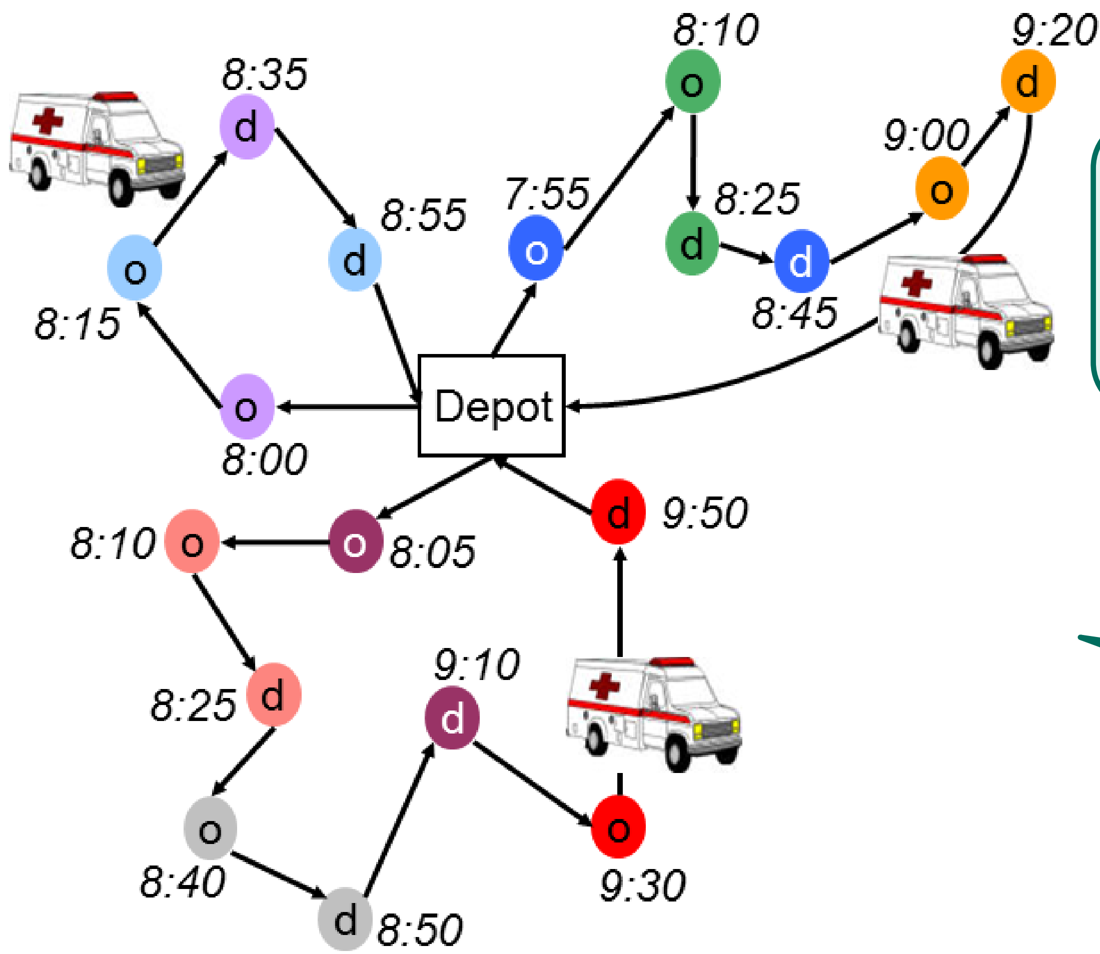
Emergency medical services

Patient Transport

Health Care Logistics



Health Care Logistics



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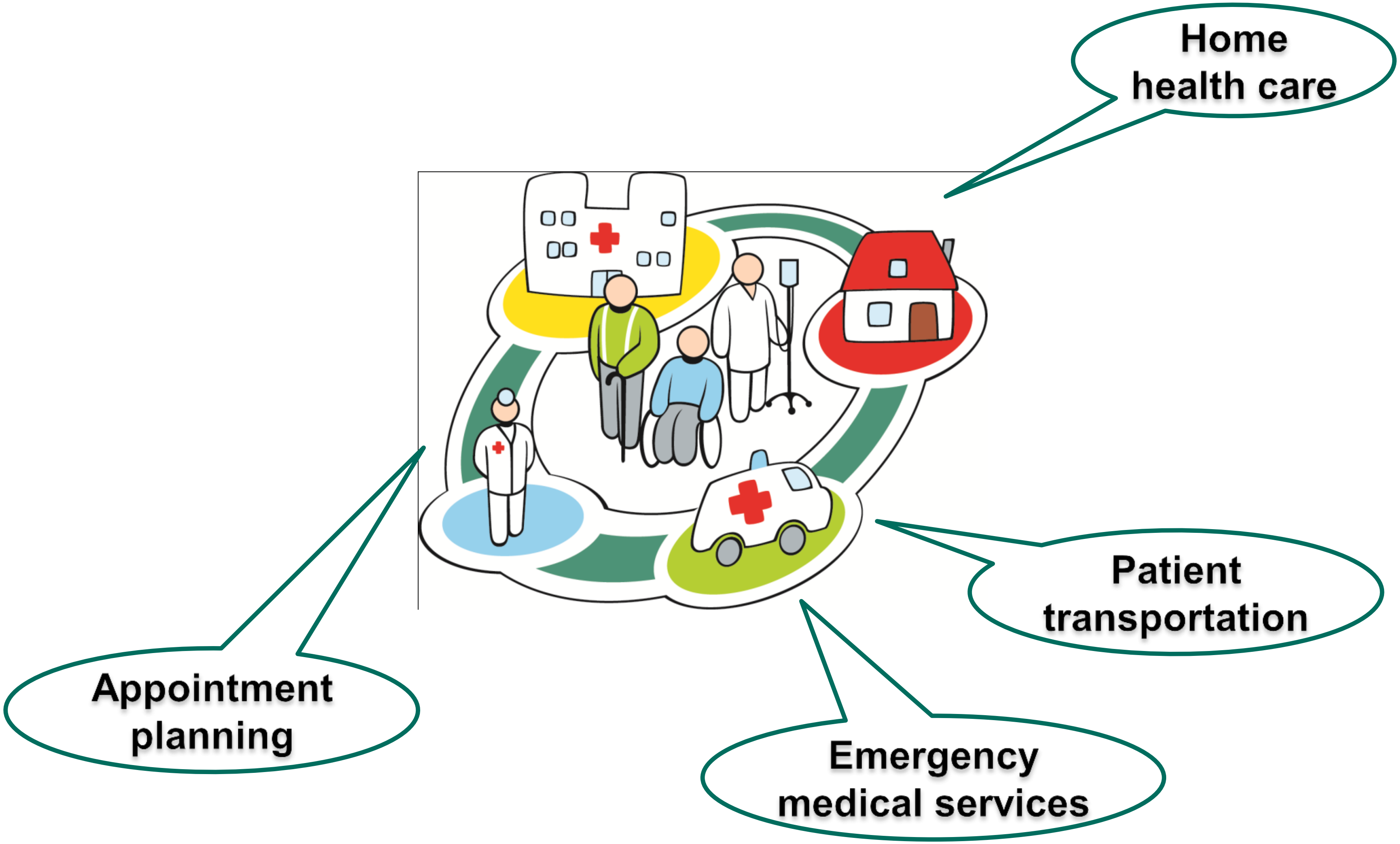
Stefan Nickel

Beaudry, A.; Laporte, G.; Melo, T. & Nickel, S., Dynamic transportation of patients in hospitals, OR Spectrum (32):70-107, 2010.

Patient transportation

Health Care Logistics



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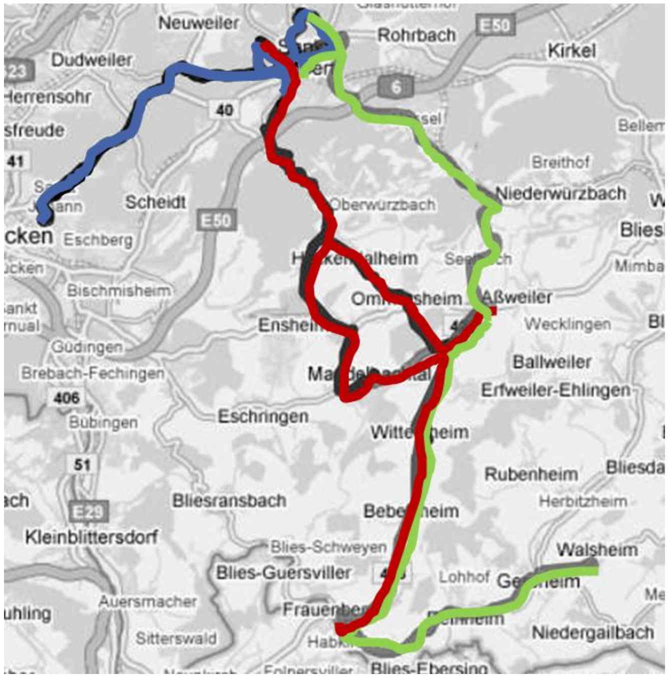

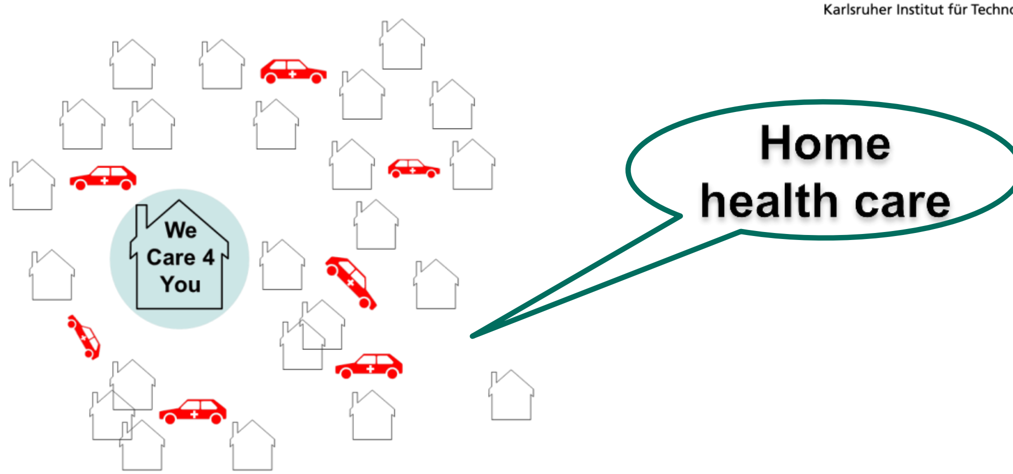

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Pfleger 1	Schicht 1				Tou										Tour 13
	Schicht 2		Tour 4		Tou									Tour 12	Tour 14
Pfleger 2	Schicht 1							Tour 13				Tour 7	Tour 9		
	Schicht 2						ır 12	Tour 14		Tour 4		Tour 8			
Pfleger 3	Schicht 1			Tour 5							Tour 5				
	Schicht 2	Tour 2				Tour 10			Tour 2				Tour 10		

Patient 1
Patient 4
Patient 2
Patient 8
…

Research Center for Information Technology
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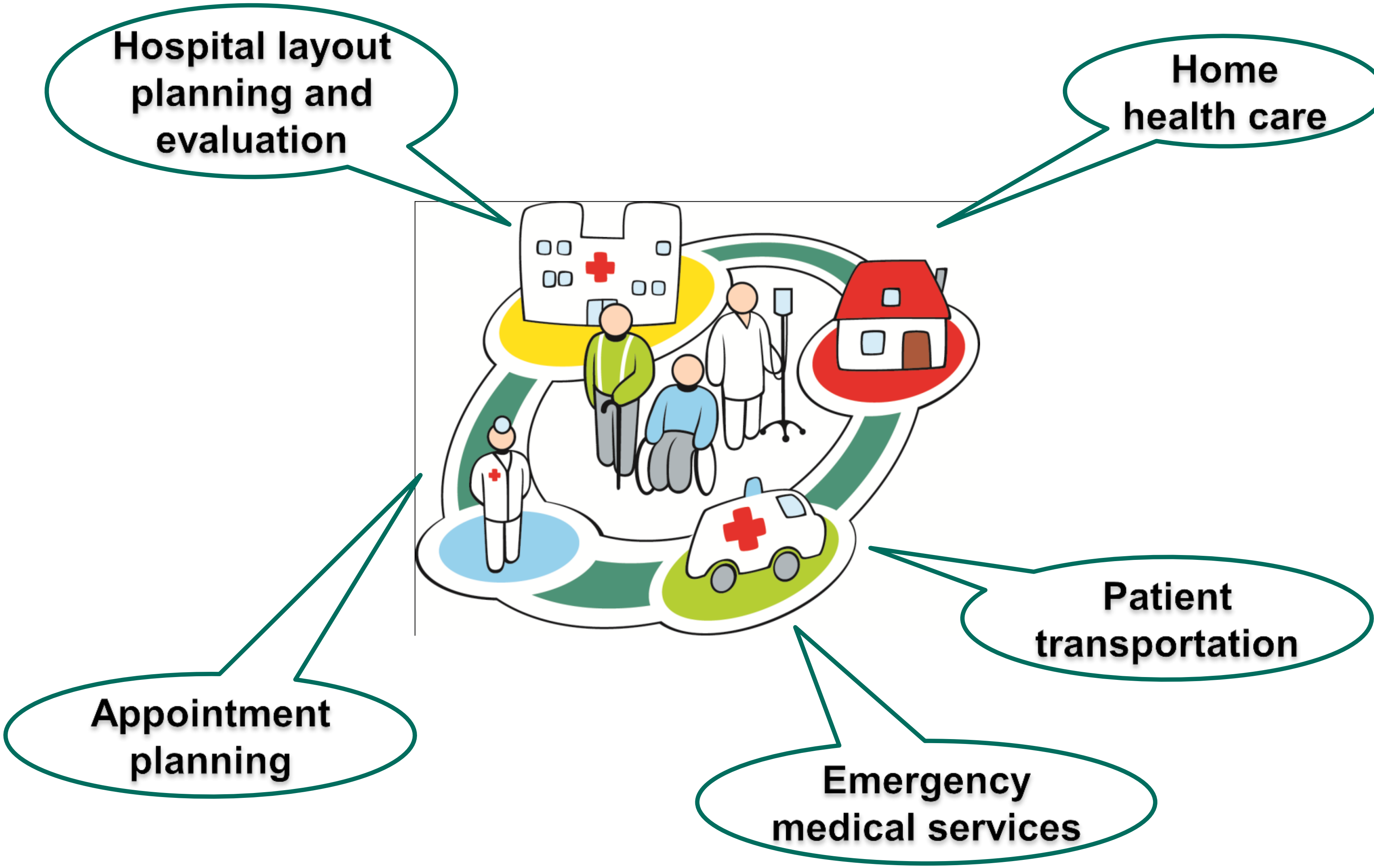
Jacqueline Wirnitzer
Patient-based nurse rostering and tour planning in home care

Health Care Logistics



Health Care Logistics

Hospital layout planning and evaluation

Research Center for Information Technology
www.fzi.de

Jacqueline Wirnitzer
Prevention of bottlenecks in hospital layouts through simulation modeling

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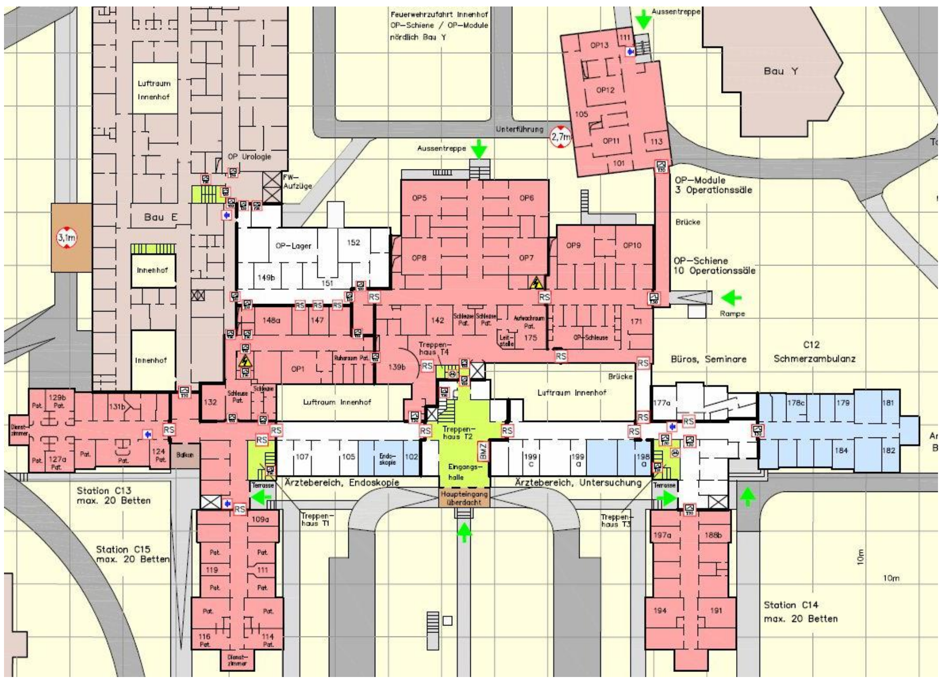
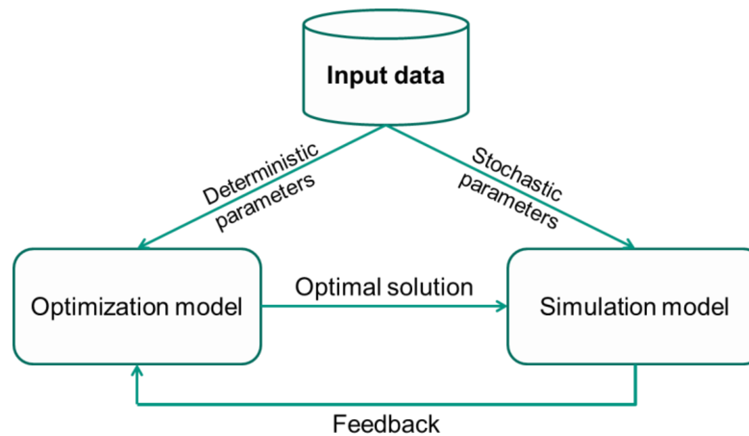
Discrete Optimization and Logistics
dol.ior.kit.edu

Ines Arnolds
Hospital layout planning: combining simulation and optimization

Arnolds, I. V., Nickel, S., “An Iterative Simulation-Optimization Approach for Hospital Layout Planning”, INFORMS Healthcare 2013, Chicago, USA.

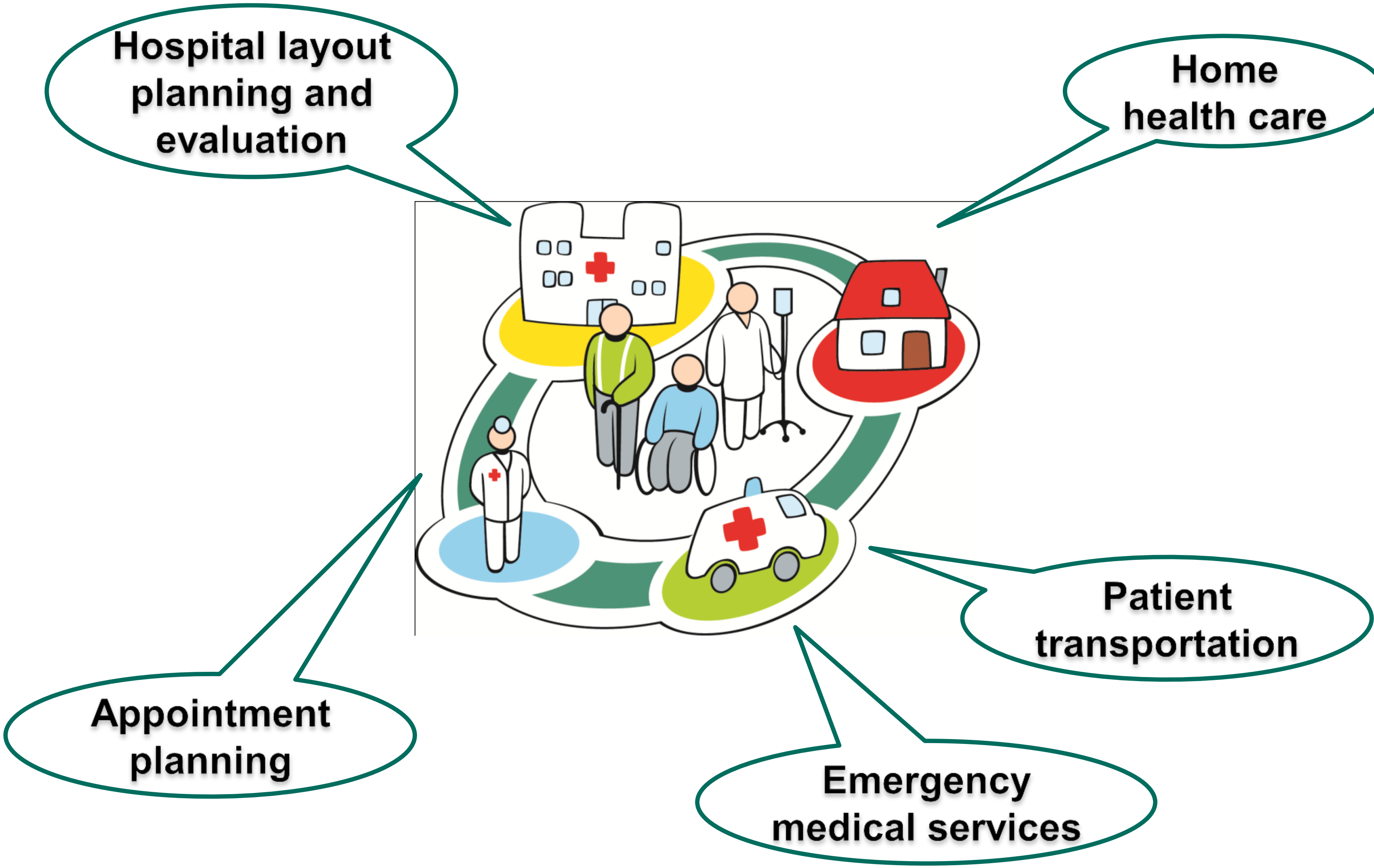
Arnolds, I. V., Nickel, S., Multi-period layout planning for hospital wards, Socio-Economic Planning Sciences (47):220-237, 2013.





Kulkarni (2012)

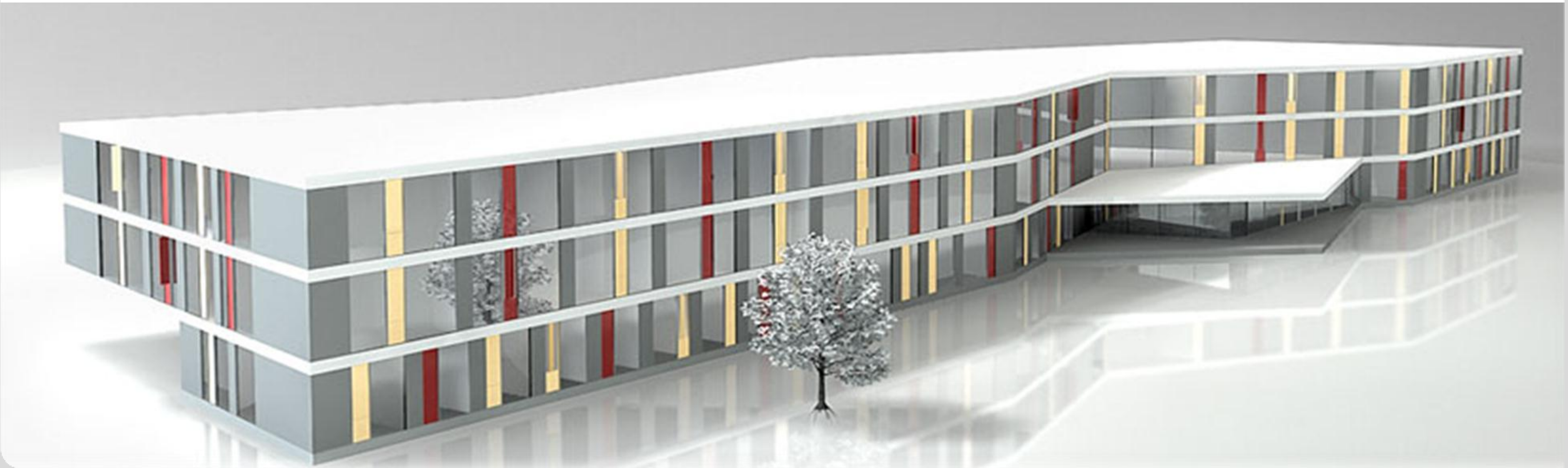
Health Care Logistics



An Iterative Simulation-Optimization Approach for Hospital Layout Planning

Stefan Nickel, Ines Arnolds

Institute of Operations Research, Discrete Optimization and Logistics

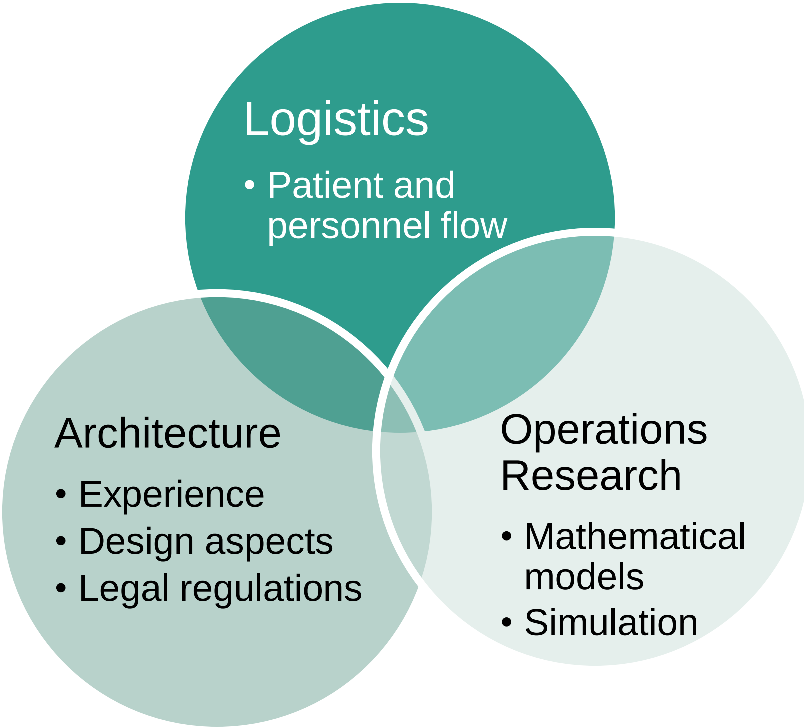


Outline

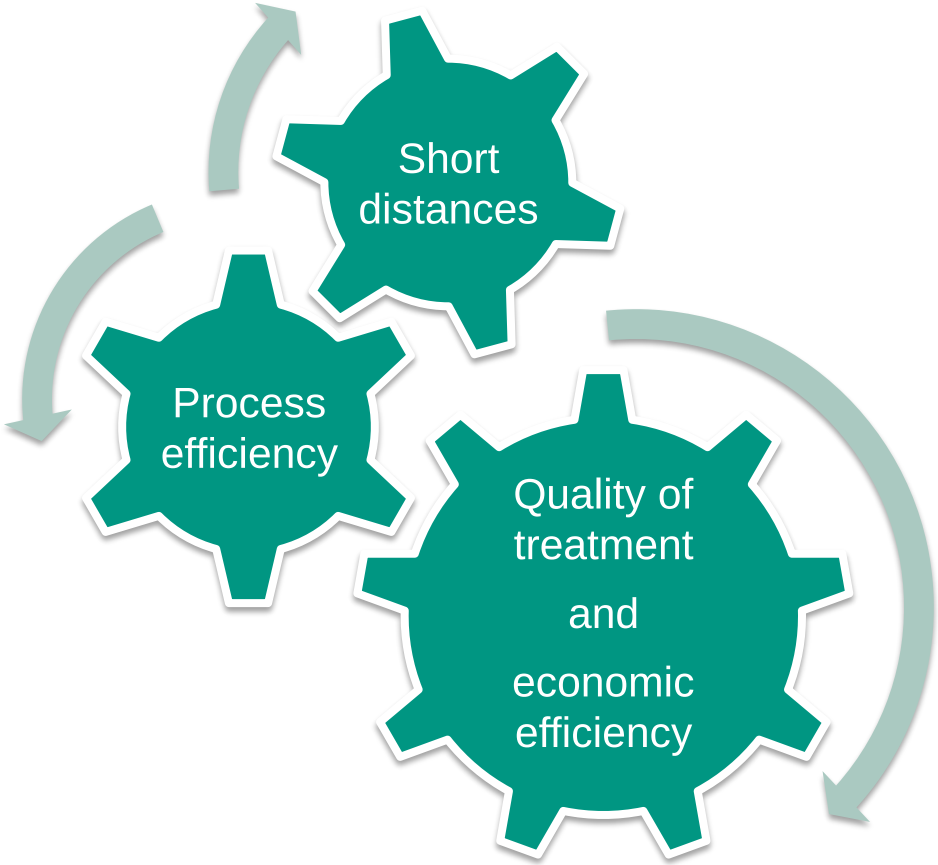
- Motivation and research questions
- Literature
- Methodology
- Models
- Preliminary results
- Summary and next steps

Motivation

- Holistic view



- Influence on daily operations, e.g. patient transportation



Motivation

Compare and improve the performance and robustness of hospital layouts for various scenarios

Studying factors by DES, which are hard to integrate in mathematical models or heuristics for hospital layout planning

Combination of

- Mathematical optimization and
- Discrete event simulation

Extrinsic configuration

- Control, capacity and number of elevators,
- Personnel elevators,
- Personnel shifts and schedules for breaks.

Stochastic influences

- Clinical pathways,
- Means and speed of transportation,
- Patient arrival rates,
- Service durations.

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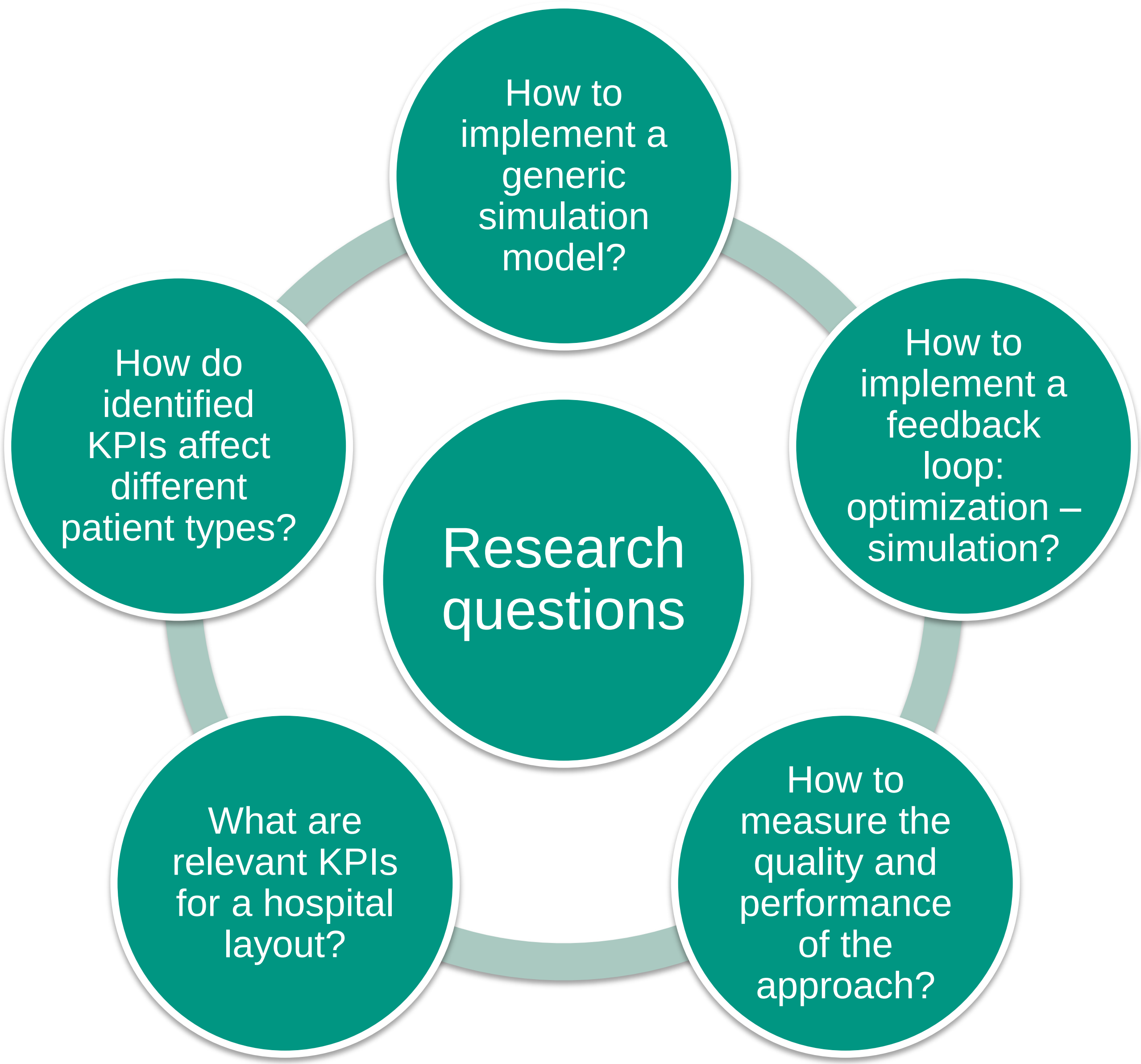
Research questions
How to implement a generic simulation model?
How to implement a feedback loop: optimization – simulation?
How to measure the quality and performance of the approach?
What are relevant KPIs for a hospital layout?
How do identified KPIs affect different patient types?

Outline

- Motivation and research questions
- **Literature**
- Methodology
- Models
- Preliminary results
- Summary and next steps

Literature

Hospital layout planning

Elshafei, A. N. 1977. “Hospital Layout as a Quadratic Assignment Problem”. Operational Research Quarterly, 28:167-179.

Gibson, I. 2007. “An Approach to Hospital Planning and Design Using Discrete Event Simulation”. *Proceedings of the 2007 Winter Simulation Conference*.

Simulation-optimization

Acar, Y., S. Kadipasaoglu, J. Day. 2009. „Incorporating uncertainty in optimal decision making: Integrating mixed integer programming and simulation to solve combinatorial problems”. *Computers & Industrial Engineering.* 56 (1):106–112.

Kulkarni, K., J. Venkateswaran. 2012: „Stochastic Job Shop Scheduling using Hybrid Simulation and Optimization Approaches“. *International Simulation Conference of India*.

Outline

- Motivation and research questions
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- **Methodology**
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Methodology

- Combining simulation and optimization

Non-iterative models

- Models interact just once
- Running either simulation or optimization first
- Using preliminary results to obtain final solution from other model

Iterative models

- Models interact multiple times
- Until stopping criterion is met

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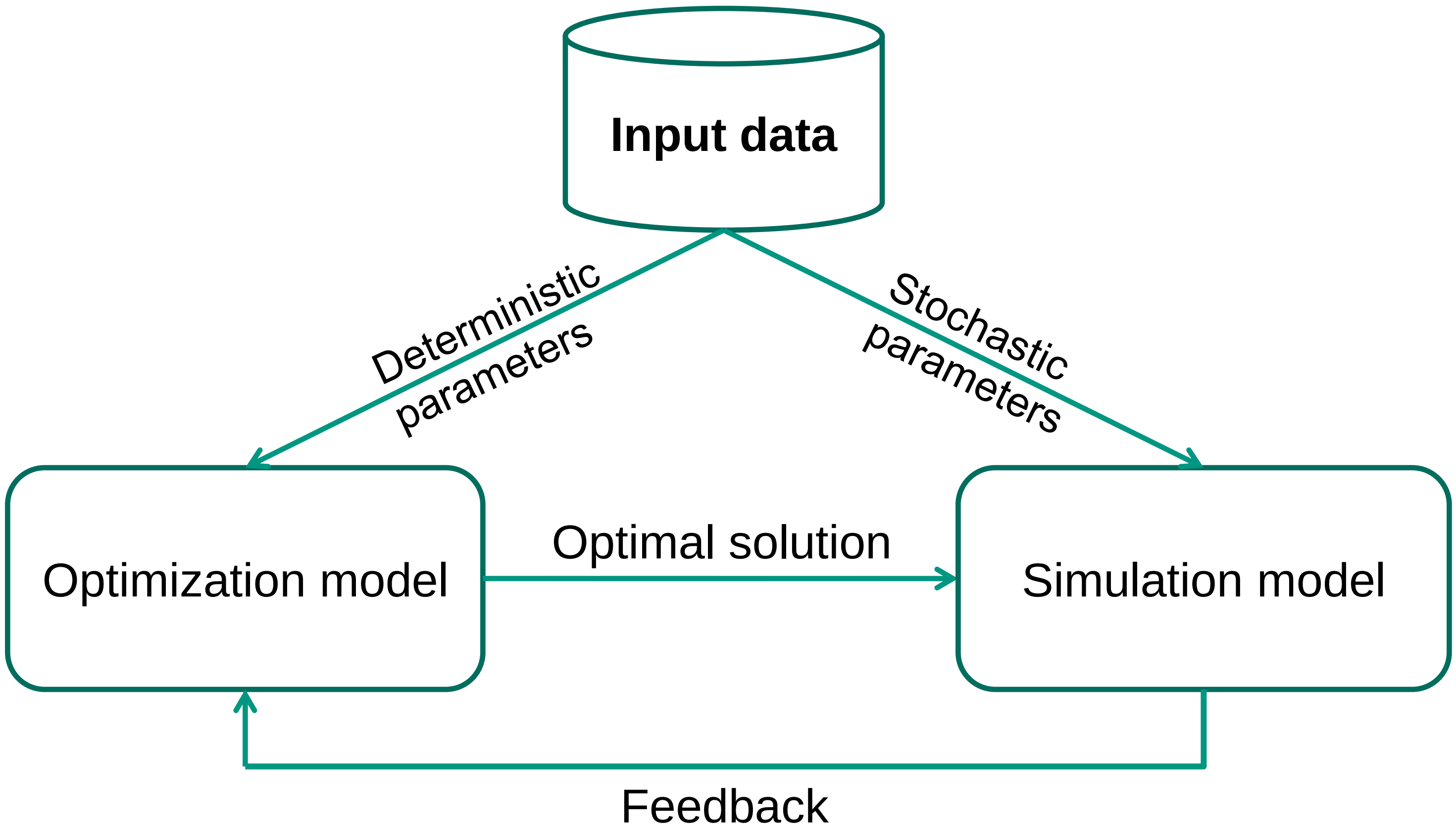
Methodology

- Iterative optimization and simulation



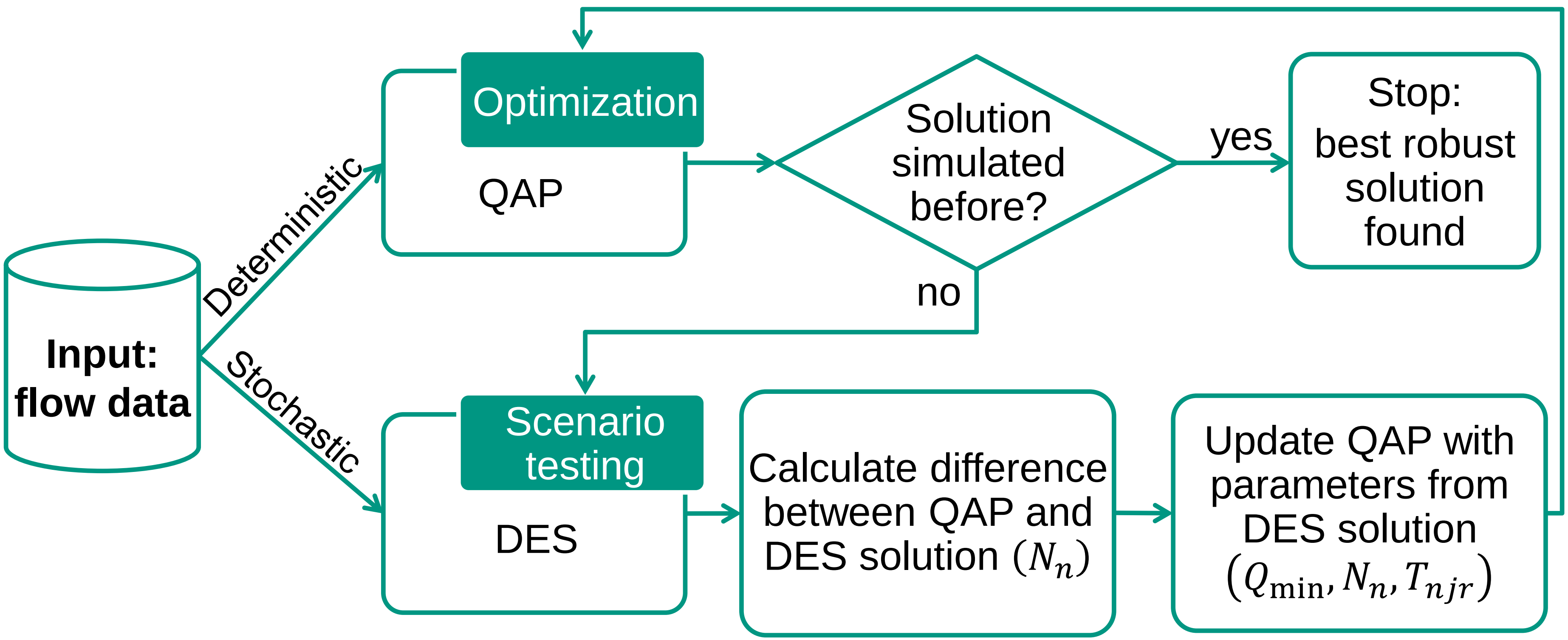
Kulkarni (2012)

Outline

- Motivation and research questions
- Literature
- Methodology
- **Models**
  - **Quadratic assignment problem**
  - **Discrete event simulation**
- Preliminary results
- Summary and next steps

Iterative simulation-optimization approach

- Objective: Robust hospital layout with short travel distances and times
- Assumption: Worse objective function value under uncertainty
  - DES: Additional patient arrivals with uncertain pathways



- Implementation: AnyLogic

Based on Acar (2009)

Models: Quadratic assignment problem (QAP)

$$\min Z = \sum_{j=1}^{m}\sum_{k=1}^{m}\sum_{l=1}^{m}\sum_{r=1}^{m} f_{jk} d_{rl} y_{jr} y_{kl} \qquad \text{Minimize total travel distance} \tag{1}$$

$$\text{s.t.} \sum_{r=1}^{m} y_{jr} = 1 \qquad \text{Each department assigned to one room} \qquad \forall j \in \{1,\ldots,m\} \tag{2}$$

$$\sum_{j=1}^{m} y_{jr} = 1 \qquad \text{Each room assigned to one department} \qquad \forall r \in \{1,\ldots,m\} \tag{3}$$

$$y_{jr} \in \{0,1\} \qquad \forall j,r \in \{1,\ldots,m\} \tag{4}$$

- Parameters:

f_{jk}	flow between departments j and k
d_{rl}	distance between rooms r and l

- Decision Variables:

$$y_{jr} \;\Big|\; \begin{cases} 1, & \text{if department } j \text{ is assigned to room } r \\ 0, & \text{otherwise} \end{cases}$$

Models: Quadratic assignment problem (QAP)

$$\min Z = \sum_{j=1}^{m}\sum_{k=1}^{m}\sum_{l=1}^{m}\sum_{r=1}^{m} f_{jk} d_{rl} y_{jr} y_{kl} \boxed{+ \sum_{n} N_n Z_n} \qquad (1)$$

Penalty: Feedback from simulation

$$\text{s.t.} \sum_{r=1}^{m} y_{jr} = 1 \qquad \forall j \in \{1,\dots,m\} \qquad (2)$$

$$\sum_{j=1}^{m} y_{jr} = 1 \qquad \forall r \in \{1,\dots,m\} \qquad (3)$$

$$y_{jr} \in \{0,1\} \qquad \forall j, r \in \{1,\dots,m\} \qquad (4)$$

- Parameters:

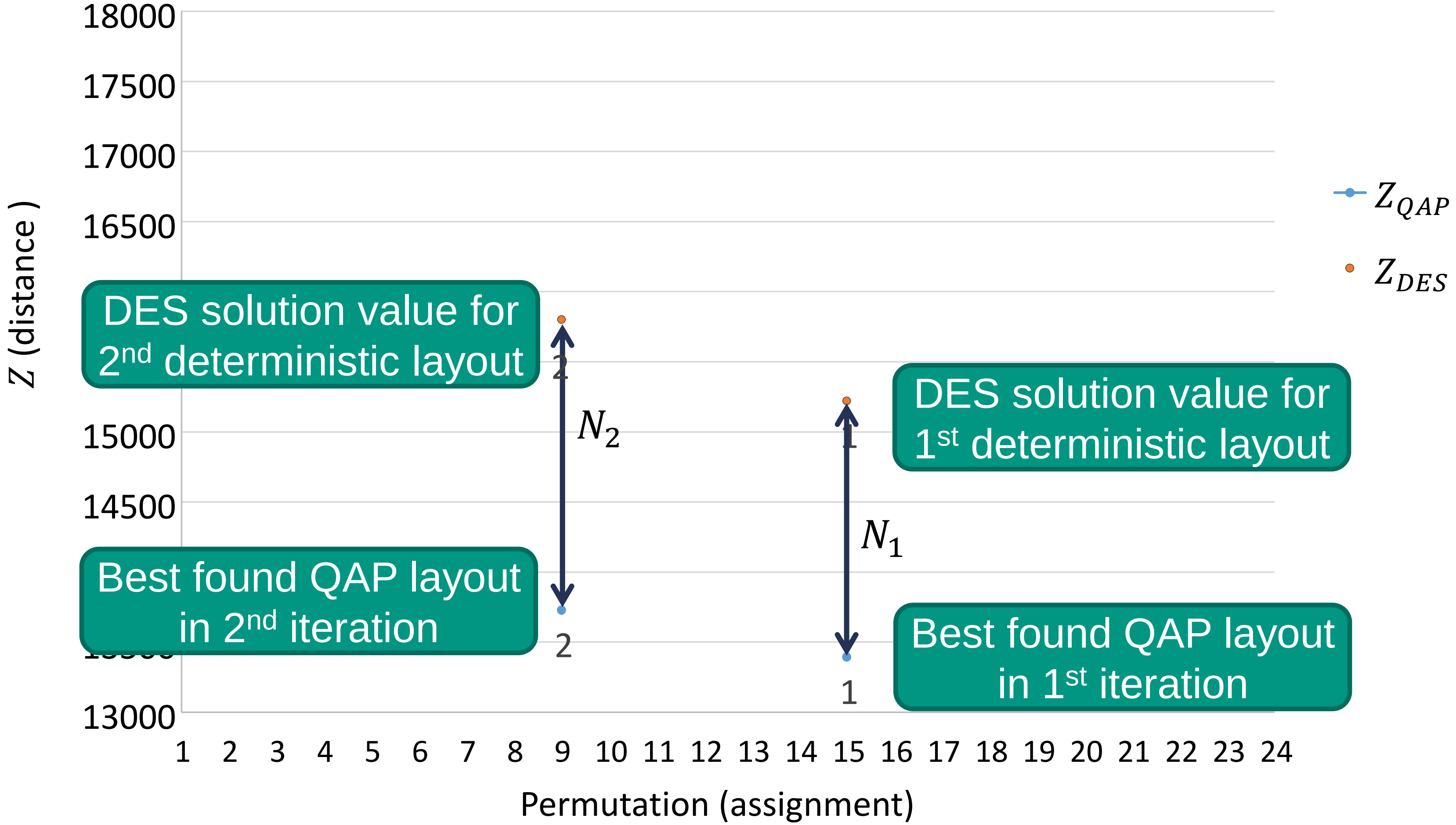
N_n	impact of uncertainty found by simulation for candidate solution n

- Decision Variables:

Z_n	binary variable for incorporating cost of uncertainty for candidate solution n: $\begin{cases} 1, & \text{if layot currently considered by QAP was suggested in a previous iteration} \\ 0, & \text{otherwise} \end{cases}$

Models: Quadratic assignment problem (QAP)

- Example: Influence of penalty N_n



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Models: Quadratic assignment problem (QAP)

$$\min Z = \sum_{j=1}^{m} \sum_{k=1}^{m} \sum_{l=1}^{m} \sum_{r=1}^{m} f_{jk} d_{rl} y_{jr} y_{kl} + \sum_{n} N_n Z_n \qquad (1)$$

$$\text{s.t.} \sum_{r=1}^{m} y_{jr} = 1 \qquad \forall j \in \{1, \dots, m\} \qquad (2)$$

$$\sum_{j=1}^{m} y_{jr} = 1 \qquad \forall r \in \{1, \dots, m\} \qquad (3)$$

$$y_{jr} \in \{0, 1\} \qquad \forall j, r \in \{1, \dots, m\} \qquad (4)$$

Determine decision variables Z_n

$$\sum_{j} \sum_{r} (2T_{njr} y_{jr} - y_{jr} - T_{njr}) \leq Z_n - 1 \qquad \forall n \in \{1, \dots, I\} \qquad (5)$$

$$\sum_{j} \sum_{r} (2T_{njr} y_{jr} - y_{jr} - T_{njr}) \geq M(Z_n - 1) \qquad \forall n \in \{1, \dots, I\} \qquad (6)$$

- Parameters:

T_{njr}	$\begin{cases} 1, & \text{if binary variable } y_{jr} \text{ in candidate solution } n \text{ is } 1 \\ 0, & \text{otherwise} \end{cases}$
I	# iterations

Models: Quadratic assignment problem (QAP)

$$\min Z = \sum_{j=1}^{m}\sum_{k=1}^{m}\sum_{l=1}^{m}\sum_{r=1}^{m} f_{jk} d_{rl} y_{jr} y_{kl} + \sum_{n} N_n Z_n \qquad (1)$$

$$\text{s.t.} \quad \sum_{r=1}^{m} y_{jr} = 1 \qquad \forall j \in \{1,\dots,m\} \quad (2)$$

$$\sum_{j=1}^{m} y_{jr} = 1 \qquad \forall r \in \{1,\dots,m\} \quad (3)$$

$$y_{jr} \in \{0,1\} \qquad \forall j, r \in \{1,\dots,m\} \quad (4)$$

$$\sum_{j}\sum_{r} (2T_{njr} y_{jr} - y_{jr} - T_{njr}) \leq Z_n - 1 \qquad \forall n \in \{1,\dots,I\} \quad (5)$$

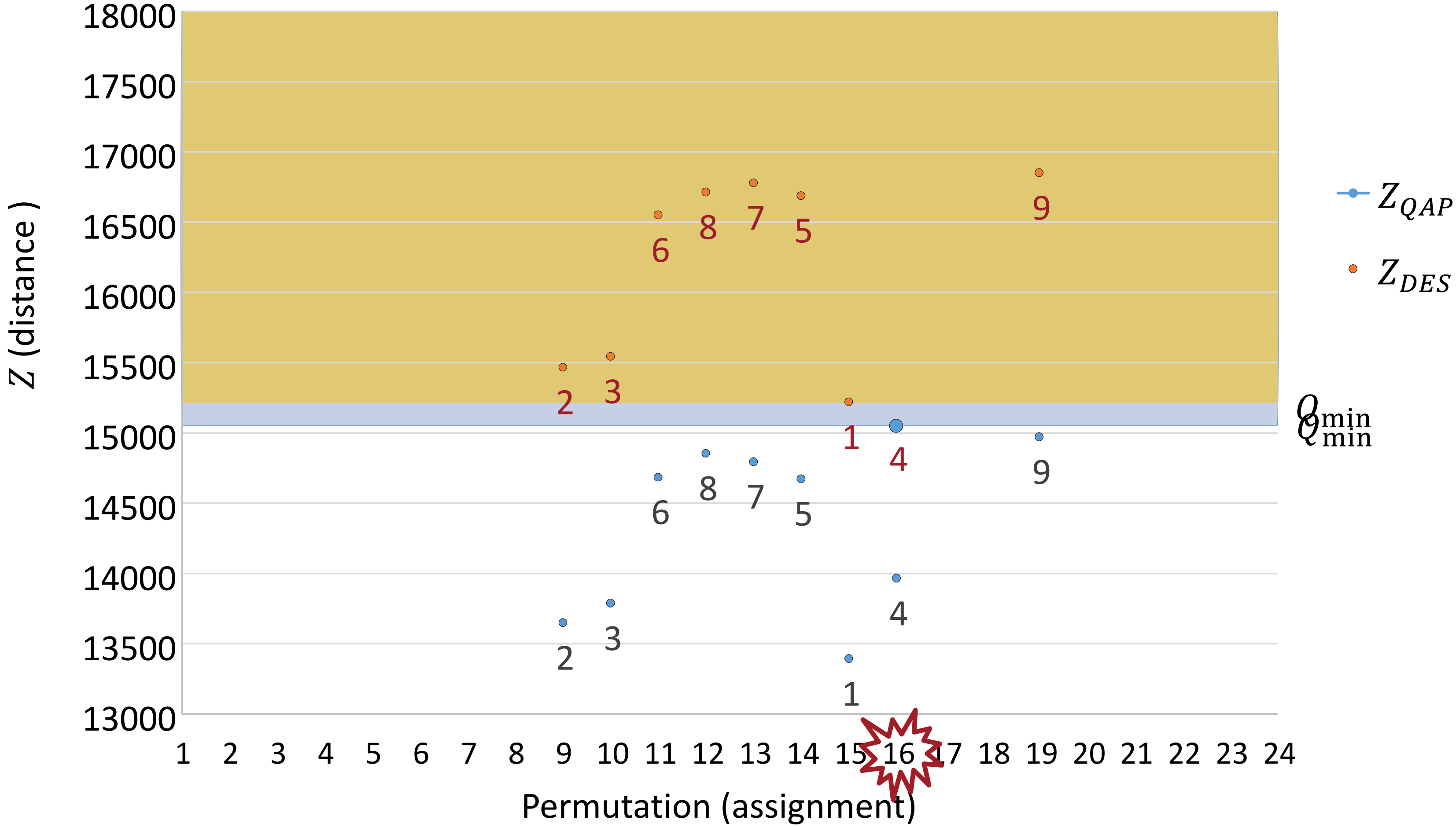
$$\sum_{j}\sum_{r} (2T_{njr} y_{jr} - y_{jr} - T_{njr}) \geq M(Z_n - 1) \qquad \forall n \in \{1,\dots,I\} \quad (6)$$

$$\boxed{Z \leq Q_{min} \quad \text{Min. cost of QAP} \leq \text{best found solution of DES}} \quad (7)$$

- Parameters: $\boxed{Q_{min} \mid \text{minimum total cost obtained so far from simulation}}$

Models: Quadratic assignment problem (QAP)

- Example: Influence of $Q_{\min}$



Model: Discrete event simulation (DES)

- Parameters
  - 3 patient types: Walking, wheelchair, bed
  - Individual speed per patient type
  - Individual weights for elevator usage per patient type
  - Arrival rates per patient type
  - Transition probabilities

Outline

- Motivation and research questions
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- Models
- **Preliminary results**
  - Simulation-optimization approach
  - Focusing on elevators in DES model
- Summary and next steps

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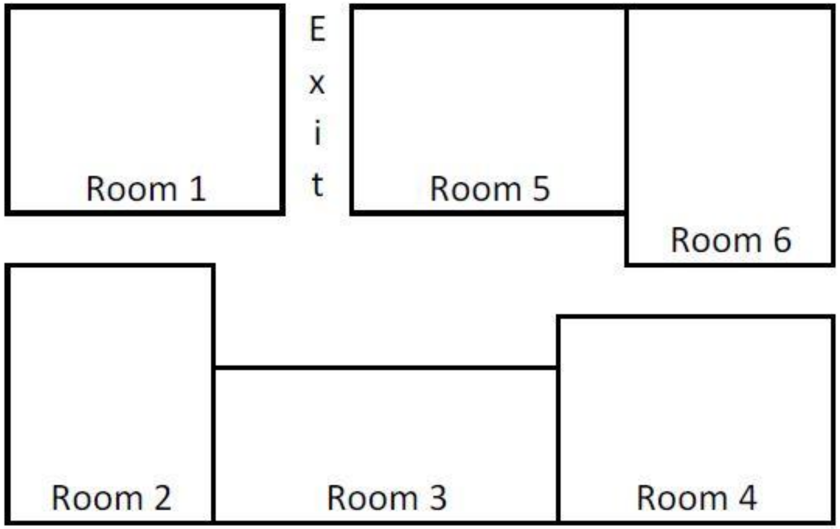
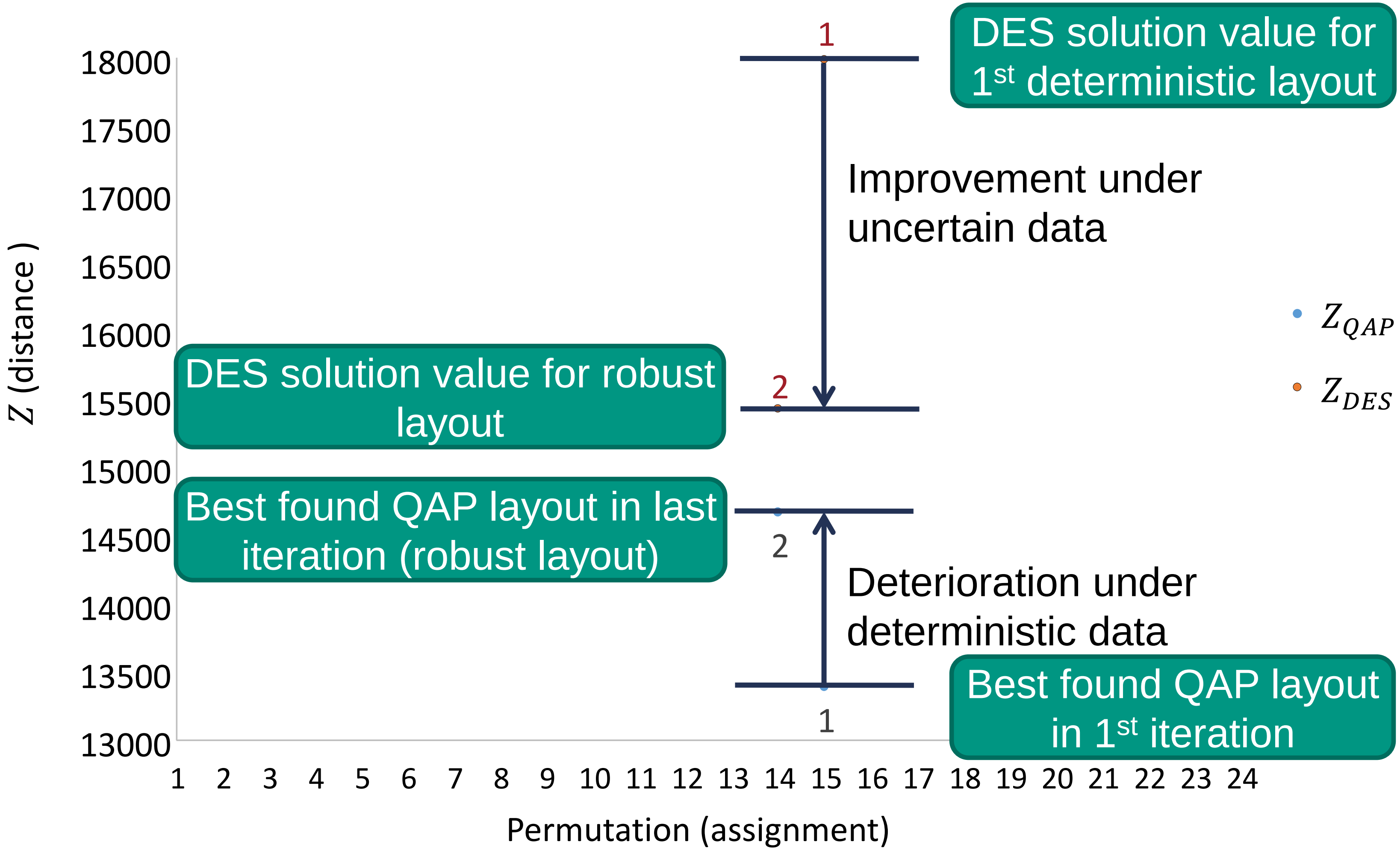
Preliminary results: Simulation-optimization approach

- Setting
  - Layout: One floor: 6 rooms and entry/exit
  - Randomly generated flow matrix
  - Random transition probabilities



Preliminary results: Simulation-optimization approach

- Performance measures



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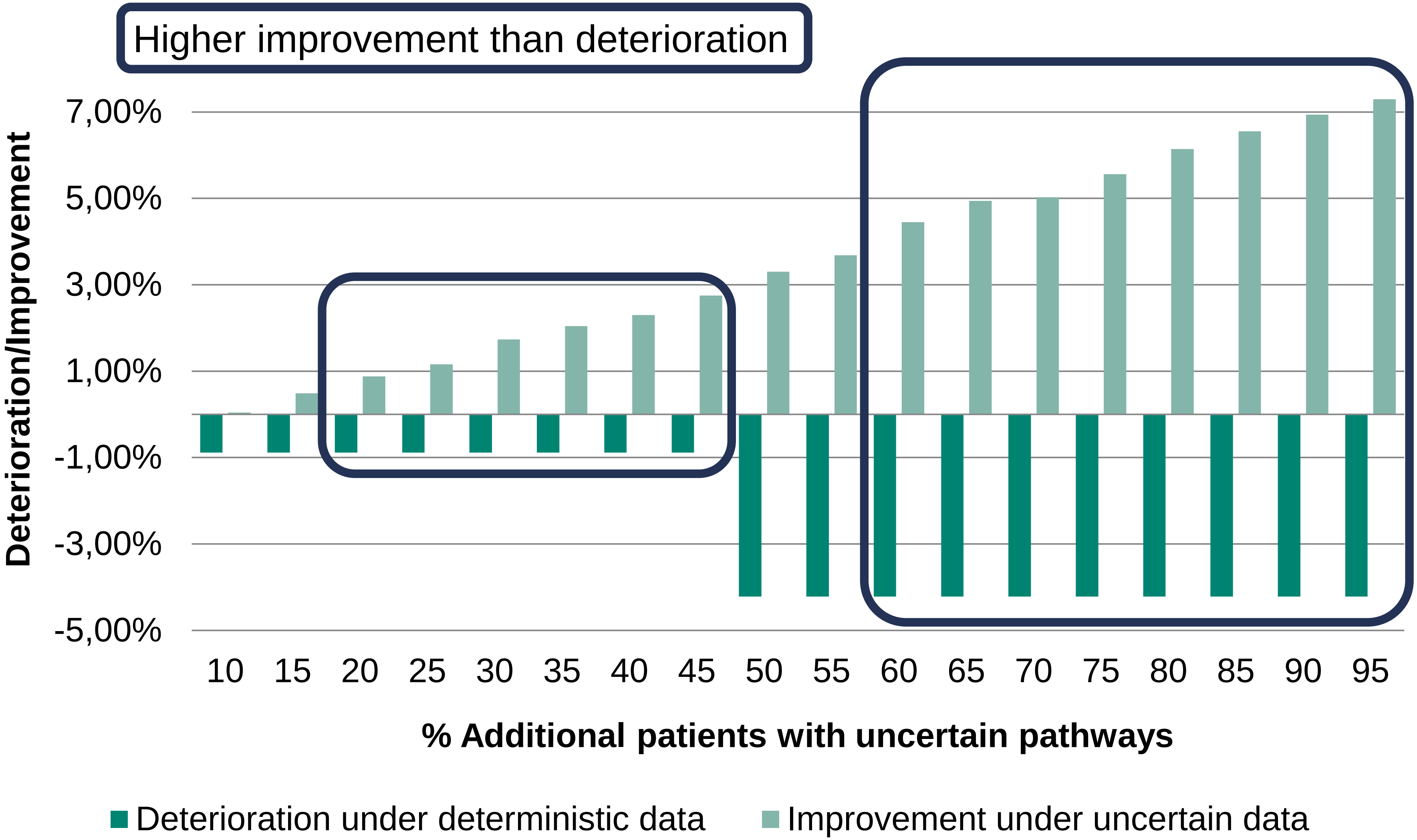
Preliminary results: Simulation-optimization approach



Preliminary results:
Focusing on elevators in DES model

- Setting

Layout

- 4 different layouts where locations of wards, surgical units and functional departments are interchanged

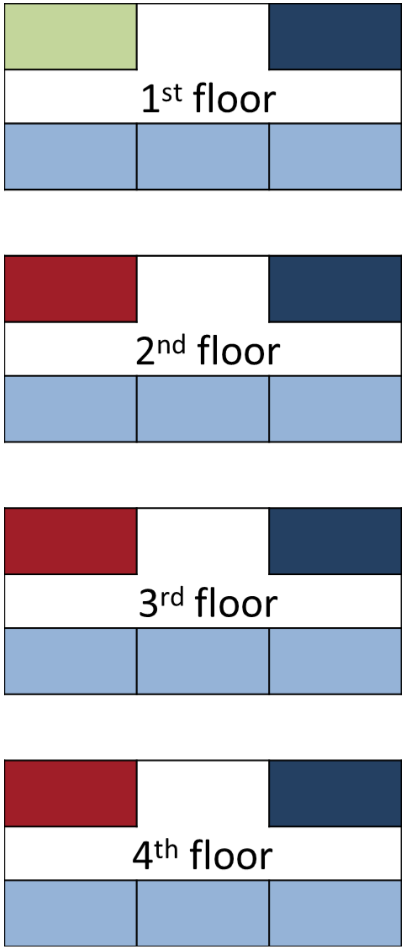
Elevators

- Varying number vs. capacities of elevators

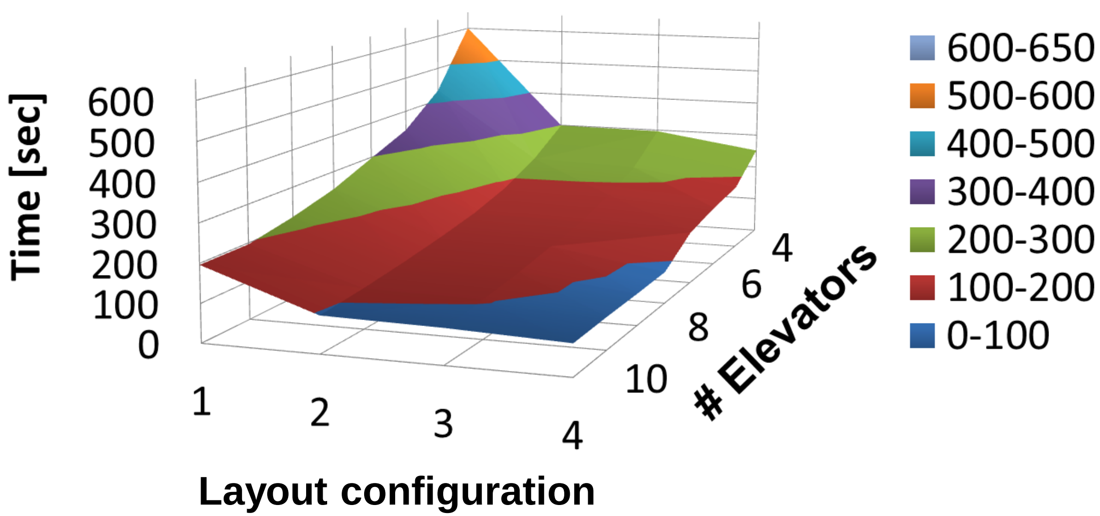
20 departments on 4 floors

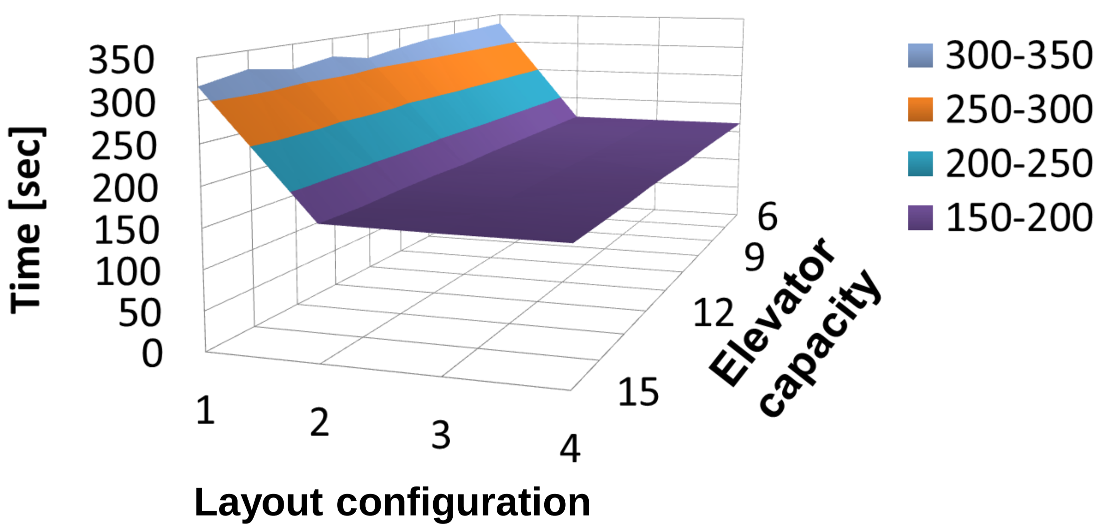
 # Replications

- 10 replications for each scenario



Preliminary results: Focusing on elevators in DES model





Sensitivity analysis

- Average total waiting time for elevator

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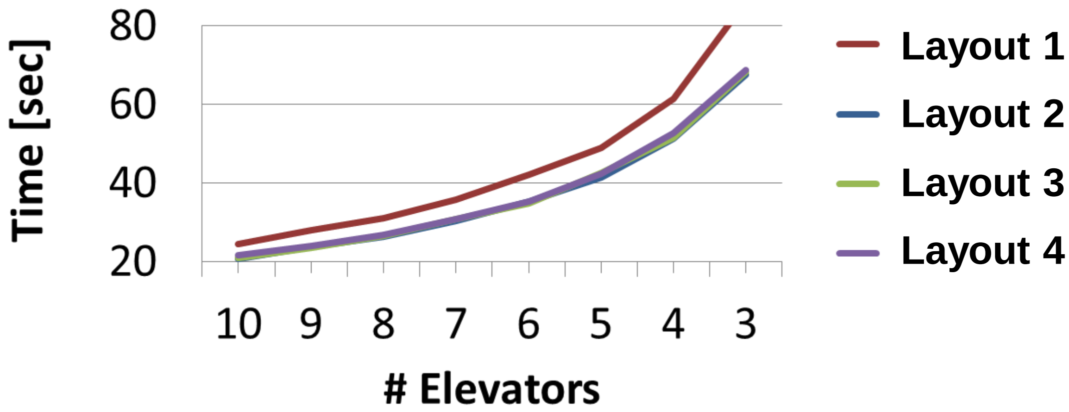
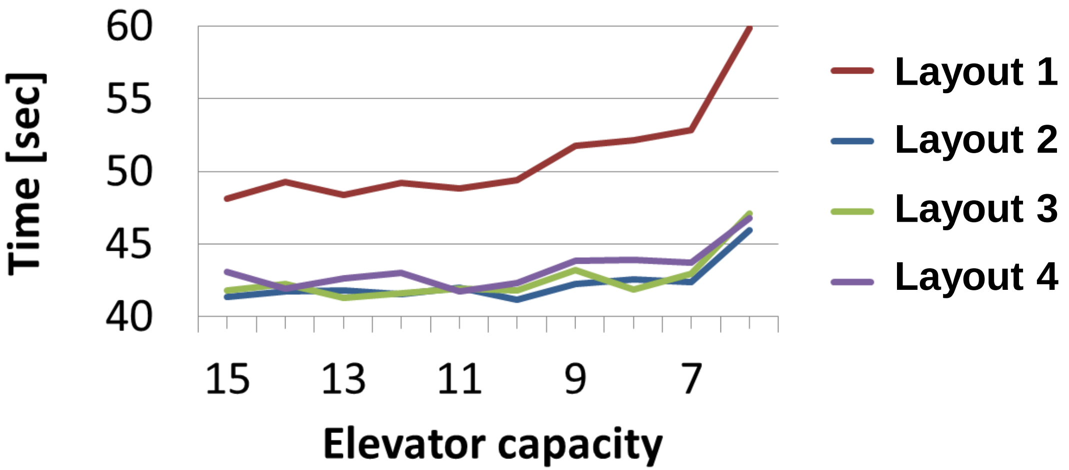
Preliminary results: Focusing on elevators in DES model





Sensitivity analysis

- Average waiting time for elevator

Outline

- Motivation and research questions
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Summary

- Robust hospital layout via simulation-optimization approach

For people in charge of hospital planning (architects, hospital managers, and engineers)

Decision support tool

Patient satisfaction and economic efficiency

Improved operational processes, e.g. more efficient transport of patients and material

Considering the dynamic environment

- Additional patients
- Uncertain pathways (changing diseases, courses of diseases as well as treatment methods)

Working quality and staff satisfaction

Utilize working time more effectively and efficiently

Next steps

- Modify QAP to solve larger instances
  - Practically relevant constraints
  - Symmetry breaking constraints

- DES model: Measurement of other relevant KPI’s
  - Travel times
  - Personnel: Travel distances/times with/without patients
  - Fair layout: Regarding KPI’s for different patient types
  - …

- Tests on real-world data
  - Flow data
  - Transition matrices and transition probabilities

An Iterative Simulation-Optimization Approach for Hospital Layout Planning

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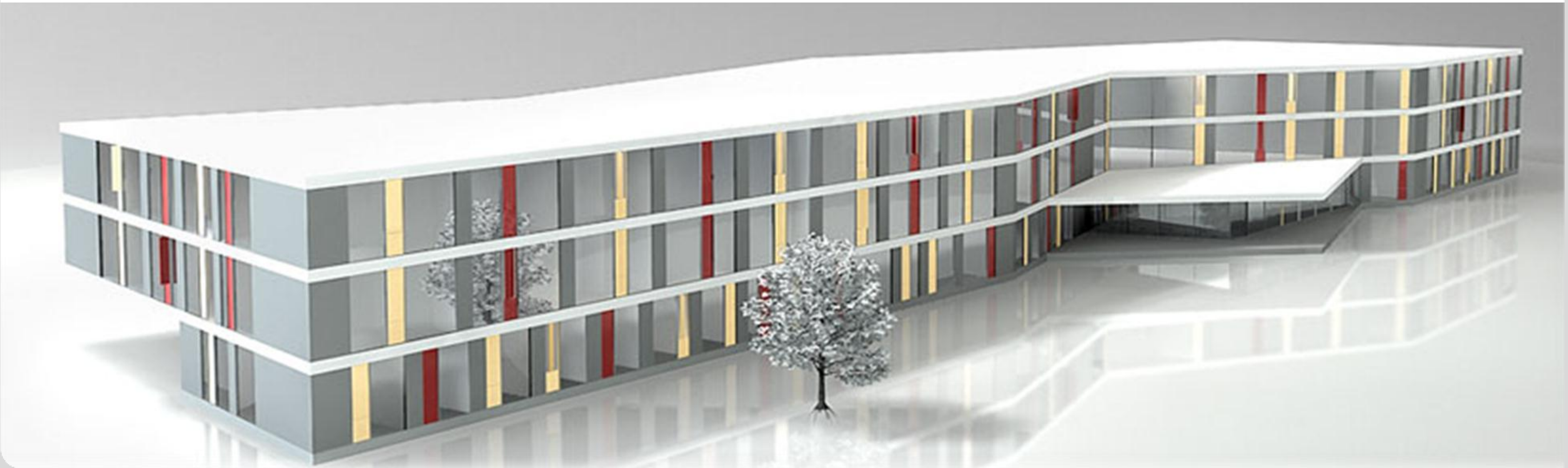
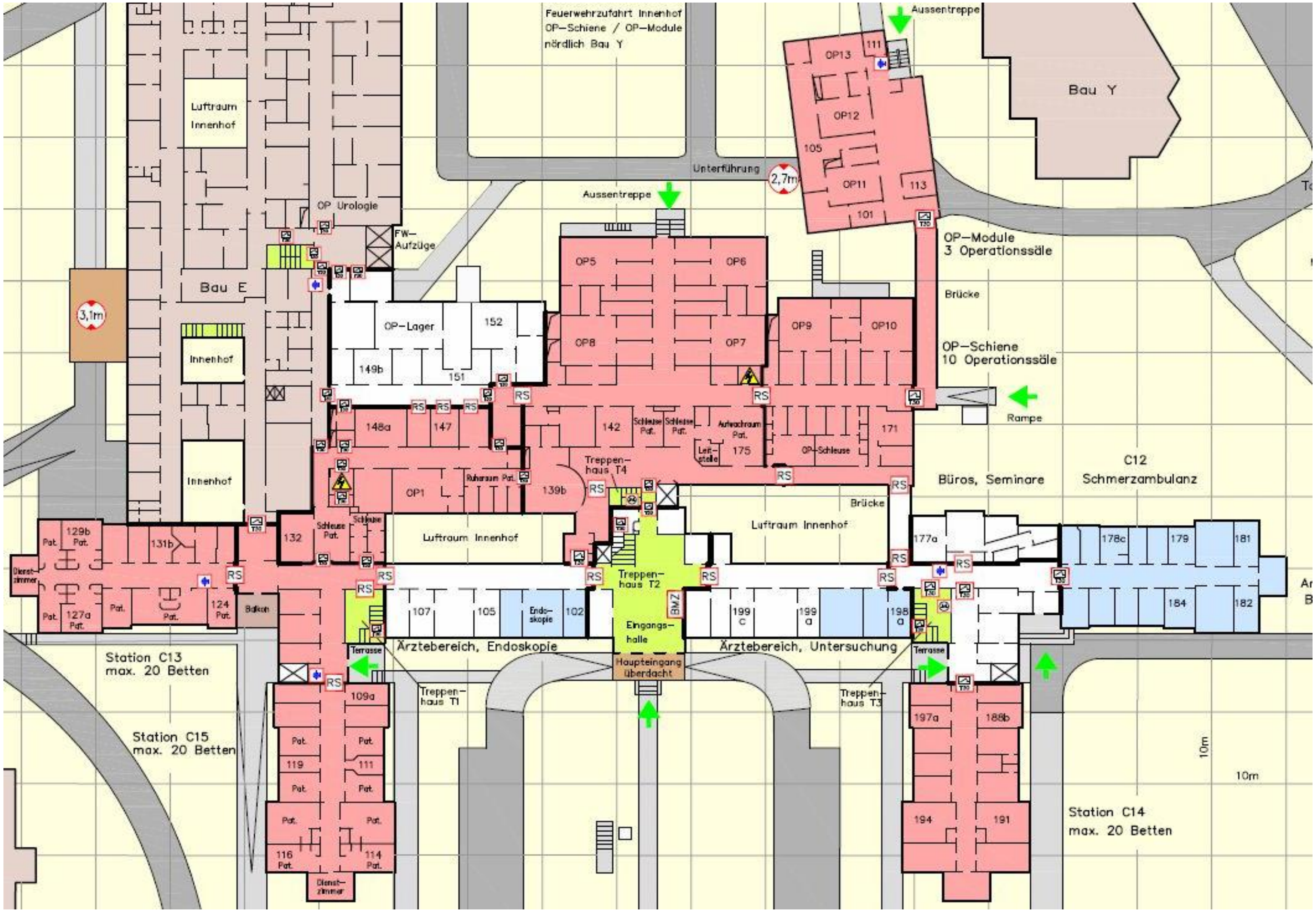


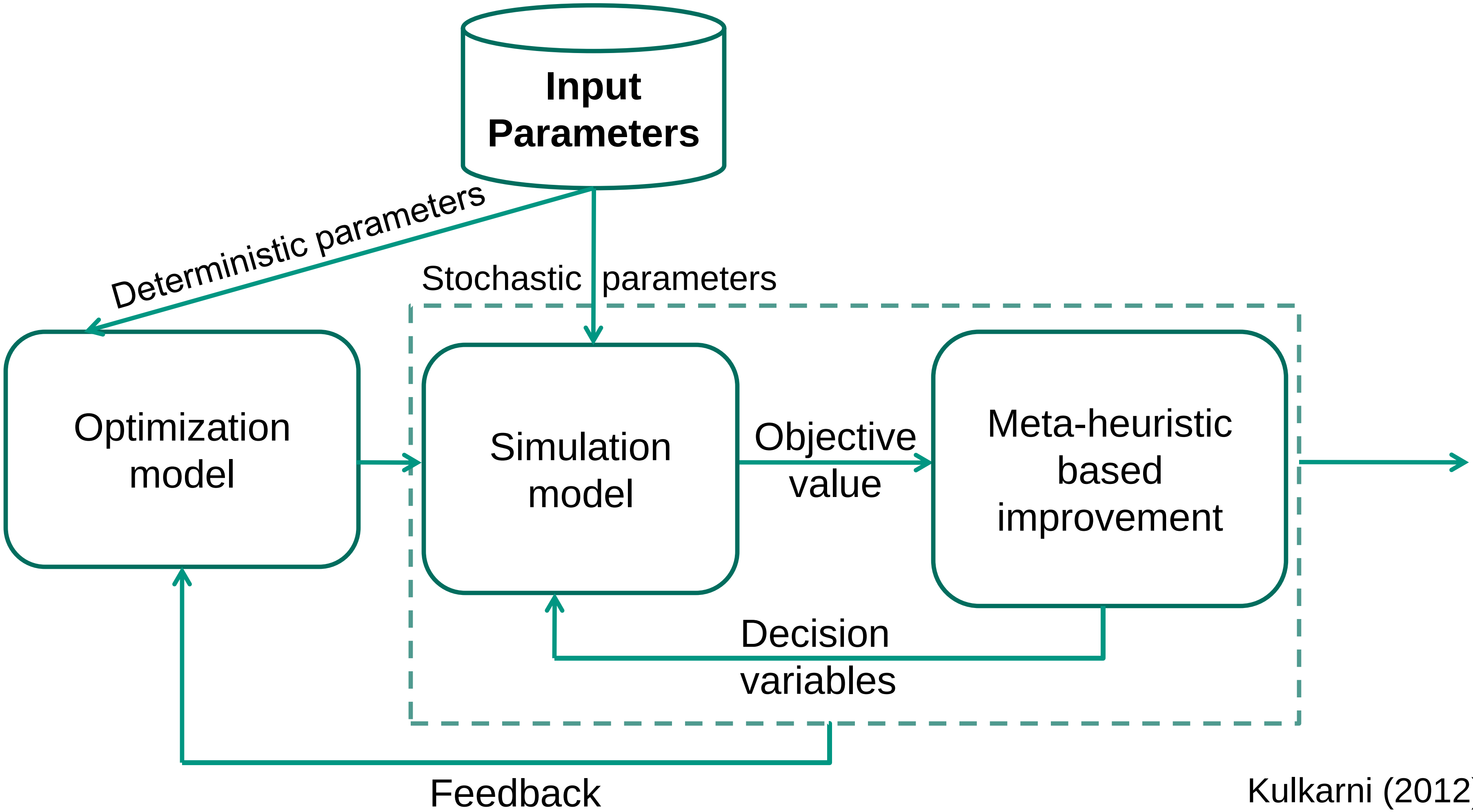
Backup

Hospital layout planning: Example



Methodology

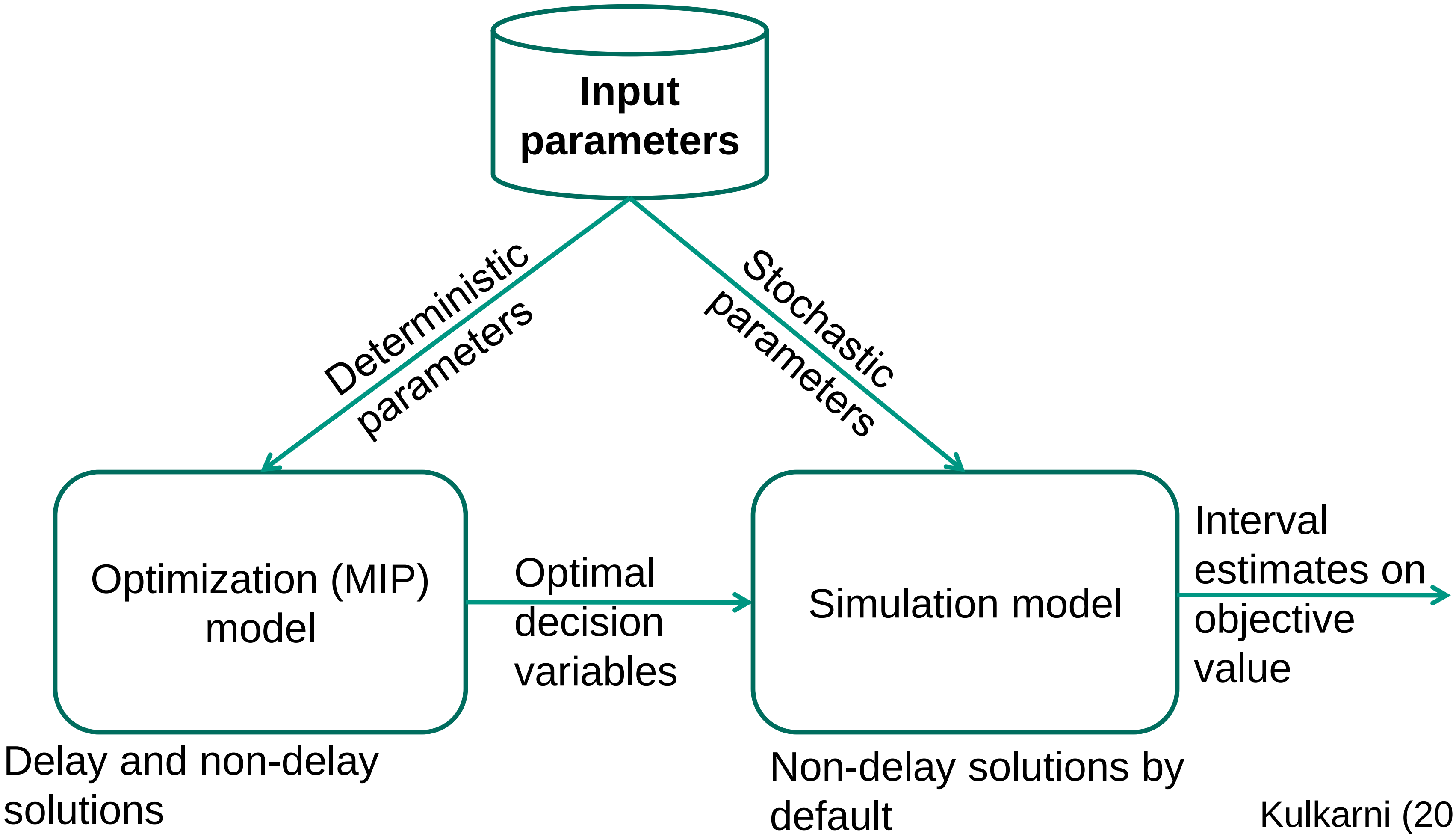
- Iterative optimization and simulation-based optimization



Kulkarni (2012)

Hybrid models

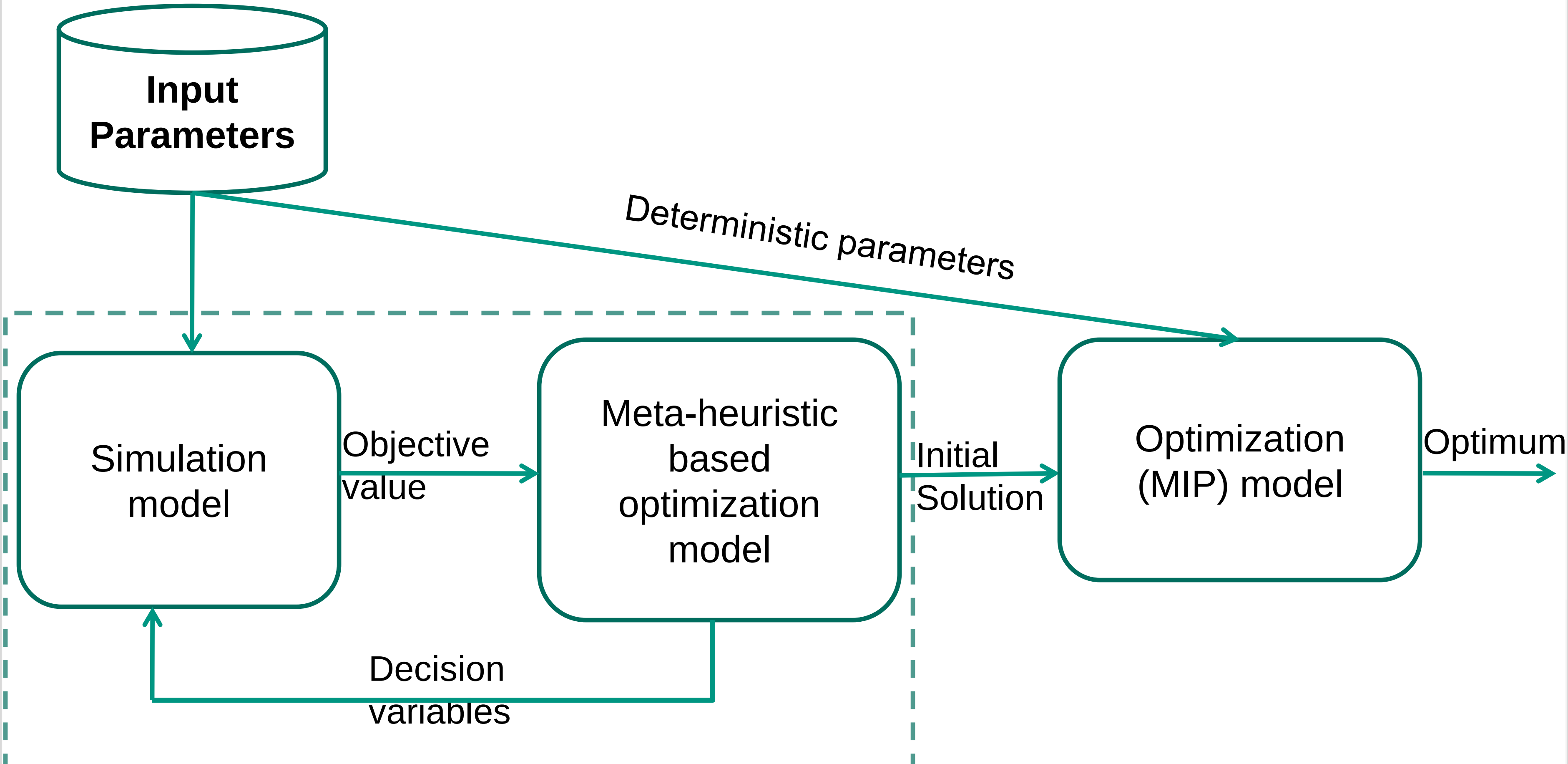
- Non-iterative optimization and simulation



Kulkarni (2012)

Hybrid models

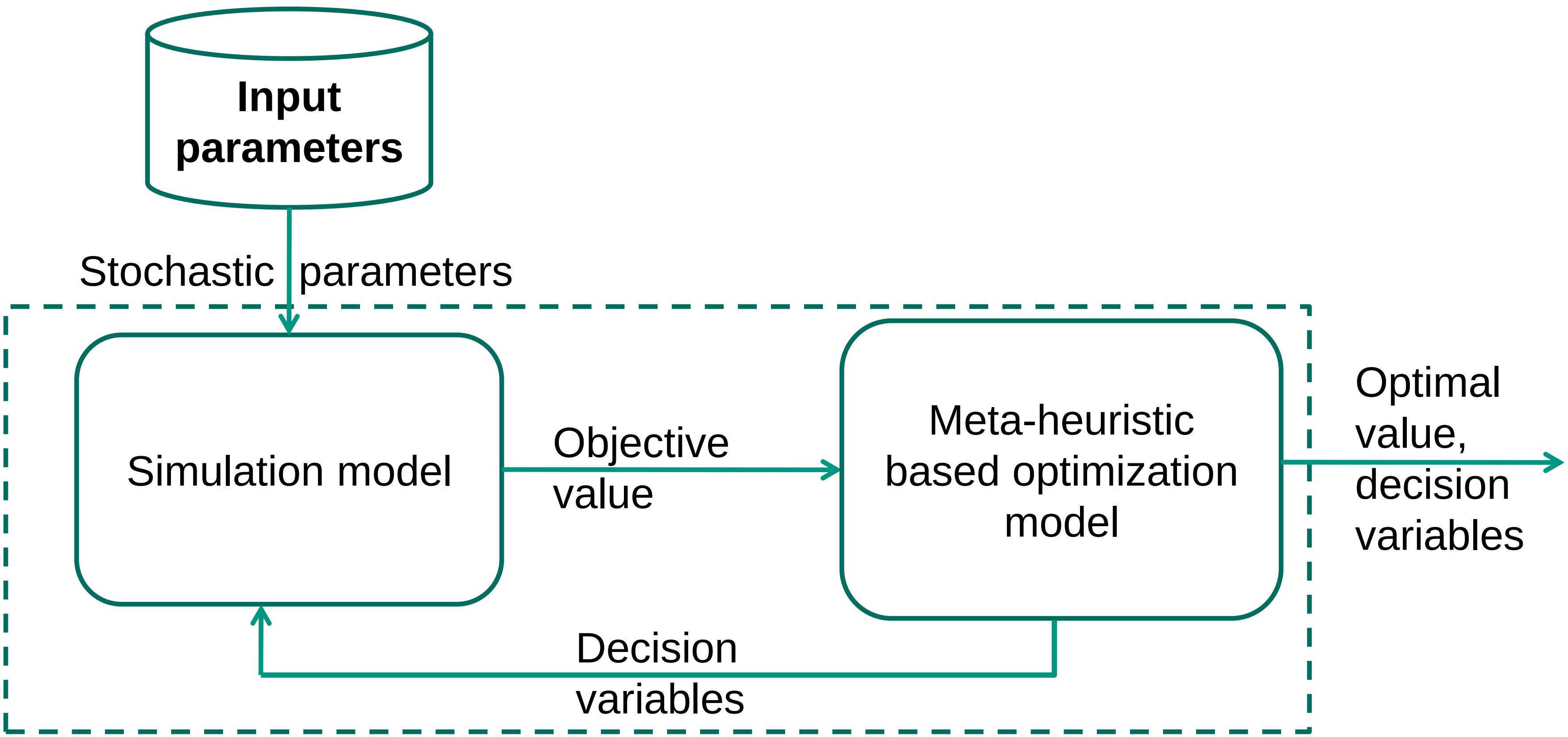
- Non-iterative simulation-based optimization and optimization



Kulkarni (2012)

Hybrid models

- Iterative simulation-based Optimization



Kulkarni (2012)

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$$\text{s.t.} \sum_{r=1}^{m} y_{jr} = 1 \qquad \forall j \in \{1,\dots,m\} \quad (2)$$

$$\sum_{j=1}^{m} y_{jr} = 1 \qquad \forall r \in \{1,\dots,m\} \quad (3)$$

$$y_{jr} \in \{0,1\} \qquad \forall j,r \in \{1,\dots,m\} \quad (4)$$

$$\sum_{j}\sum_{r} (2T_{njr} y_{jr} - y_{jr} - T_{njr}) \le Z_n - 1 \qquad \forall n \in \{1,\dots,I\} \quad (5)$$

- Parameters:

T_{njr}	$\begin{cases} 1, & \text{if binary variable } y_{jr} \text{ in candidate solution } n \text{ is } 1 \\ 0, & \text{otherwise} \end{cases}$
I	# iterations

$$\boxed{(T_{njr} = y_{jr}\ \forall\ j,r) \Rightarrow (Z_n = 1)}$$

Models: Quadratic assignment problem (QAP)

$$\min Z = \sum_{j=1}^{m}\sum_{k=1}^{m}\sum_{l=1}^{m}\sum_{r=1}^{m} f_{jk} d_{rl} y_{jr} y_{kl} + \sum_{n} N_n Z_n \qquad (1)$$

$$\text{s.t.} \sum_{r=1}^{m} y_{jr} = 1 \qquad \forall j \in \{1,\dots,m\} \qquad (2)$$

$$\sum_{j=1}^{m} y_{jr} = 1 \qquad \forall r \in \{1,\dots,m\} \qquad (3)$$

$$y_{jr} \in \{0,1\} \qquad \forall j,r \in \{1,\dots,m\} \qquad (4)$$

$$\sum_{j}\sum_{r} (2T_{njr} y_{jr} - y_{jr} - T_{njr}) \le Z_n - 1 \qquad \forall n \in \{1,\dots,I\} \qquad (5)$$

$$\sum_{j}\sum_{r} (2T_{njr} y_{jr} - y_{jr} - T_{njr}) \ge M(Z_n - 1) \qquad \forall n \in \{1,\dots,I\} \qquad (6)$$

$$\boxed{(\exists\, T_{njr} \neq y_{jr}) \Rightarrow (Z_n = 0)}$$

Model: Discrete event simulation (DES)

- Parameters
  - 3 patient types: Walking, wheelchair, bed
  - Individual speed per patient type
  - Individual weights for elevator usage per patient type
  - Arrival rates per patient type
  - Transition probabilities
  - 20 departments on 4 floors:
    - Fixed
      - **Entrance**
    - Variable
      - 3 **surgical units, laboratory**
      - 4 **functional departments**
      - 12 **wards**