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USING SIMULATION IN HOSPITAL LAYOUT PLANNING

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ABSTRACT

The quality and performance of a hospital layout during daily operations highly depends on patient and personnel flows. The travelling routes are influenced by the stochasticity of clinical pathways due to the patients' recovery processes. To account for this stochasticity when planning a hospital layout, we developed a *robust optimization via simulation* approach, which is a combination of mathematical optimization, discrete event simulation (DES), and improvement heuristics. The objective of our approach is to generate a robust hospital layout through a sensitivity analysis of different layout plans in various scenarios with stochastic patient flows. Scenarios are defined by changing both input data (extrinsic configuration) and factors, which are evaluated during the simulation run (stochastic influences). For the sensitivity analysis, we construct confidence intervals on the performance measures, i.e., total travelling times for patients and personnel as well as patients' waiting times.

1 PREVIOUS STUDIES AND MOTIVATION

Hospital buildings are commonly planned by architects on a long-term perspective based on experience, design aspects and legal regulations. Hence, hospital layout planning can be classified as resource capacity planning on a strategic level (Hans, Houdenhoven, and Hulshof 2012). However, the layout also influences the quality of healthcare services on an operational level (Tompkins et al. 2010). In the literature, only few mathematical models exist to assign hospital departments to rooms, e.g., Jiang and Hu (2012). Further, most models are based on deterministic data, while patient and personnel flows are stochastic due to different treatment outcomes and patients' recovery. Hence, a hospital layout should be evaluated on its anticipated day-to-day performance through a simulation before it is built.

In healthcare delivery systems, DES is focused on two areas (Jacobson, Hall, and Swisher 2006): First, patient flow analysis within single departments to improve throughput, reduce waiting times, or increase medical staff and resource utilization. Second, asset allocation, e.g., number of beds or staffing requirements, to improve service delivery. Gibson (2006) provides a DES model to plan a hospital building that supports delivery of patient care and resource usage. Chu, Lin, and Lam (2003) developed a decision support system to evaluate and predict lift performance for existing and new hospitals, respectively. In an industrial context, Heib and Nickel (2011) applied an optimization-simulation approach in scheduling.

2 RESEARCH PROBLEM

We present an approach to compare and improve the performance of hospital layouts with a fixed number of floors and rooms of different sizes for various scenarios. We study factors, which are hard to integrate in mathematical models or heuristics for hospital layout planning by DES. These factors can be divided into *extrinsic configuration* and *stochastic influences* depending on patients' recovery (see Table 1).

In a first step, the term performance with regard to a hospital layout has to be defined. As the aim is to improve patient and personnel flows through the hospital building, we calculate the total travel times for

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Table 1: Factors to build scenarios

Extrinsic configuration	Stochastic influences
Control, number and location of elevators	Clinical pathways of patients and treatment durations
Separate elevators for the personnel	Means of transportation, e.g., wheel chairs or stretchers
Personnel shifts and schedules for breaks	Personnel intervention

patients and personnel as well as the patients' waiting times for elevators or personnel. All measures are evaluated separately for each type of patient, who is defined by the severity of illness. Thus, we can develop hospital layouts with appropriate travel distances for each patient type in order to achieve fairness.

3 METHODOLOGY

We developed a *robust optimization via simulation* approach with a loop of successive simulation and improvement steps. In the preparatory step, a mathematical model is solved to assign hospital departments to rooms based on deterministic data. Next, the loop starts with the simulation step. We developed a generic DES model, which can be easily adapted to different hospital layout plans with a fixed number of floors and rooms. The robustness of the performance of each layout under several scenarios is compared. Robustness implies that a layout plan has a good performance for different scenarios. Scenarios differ in values for the input factors introduced in Table 1. In the improvement step we apply a heuristic to find a better hospital layout. The algorithm repeats with a new simulation run, followed by analysis and improvement heuristic until the layouts converge. Sensitivity analysis is conducted and confidence intervals on the performance measures are evaluated.

4 CONTRIBUTIONS

We provide an innovative framework for hospital layout planning. A robust hospital layout plan is generated by using DES in combination with mathematical models and heuristics. The DES model can easily be adapted to different layout plans by changing the location assignment for the departments. We are considering different elevator and personnel configurations as well as stochastic influences to generate robust layouts. The performance can also be evaluated in terms of fairness for different patient types.

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