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Using Discrete Event Simulation to evaluate Operating Theater Layout

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Abstract: The layout planning of an organization is known to have a great impact on its quality and performance during daily operations. The Operating Theater (OT) is an organization characterized by a fluctuating production and unpredictability of care demand. This unpredictability of populations' needs has an impact on the required human and material resources and makes the OT a dynamic environment. To deal with this stochastic property when planning the OT layout, we developed a robust optimization approach combining mathematical programming, discrete event simulation (DES), and improvement heuristics. The model aims to generate a robust OT layout considering various scenarios with stochastic patient flows.

Keywords: Operating Theater Layout Problem; simulation; ARENA; OptQuest; Healthcare.

1. INTRODUCTION

The healthcare industry is one of the largest and fastest-growing industries in the world. Nowadays, healthcare systems need to model their organization, to analyze their operation and to detect malfunctions. Building a new hospital gives opportunities to match the OT layout with the desired logistical concept to be suitable to deal with all the flows of patients, staff and material. Otherwise, the layout cannot be rearranged very easily and only with high investment cost.

Designing an OT layout is a challenging task because of the uncertainties concerning future numbers of patients. Thus, the issue that arises is how to guarantee that the layout of an OT stays appropriate for care delivery in the future? In order to ascertain its compatibility, it would be useful to have an evaluation method for the assessment of the flexibility of the OT layout and it capacity to meet the unpredictability of populations' needs. Computer simulation is one of the most widely used tool for evaluating and improving the performance of healthcare systems.

The Discrete Event Simulation is a technique of building a computer representation of the studied system (OT in our case), in order to observe its behavior under well defined conditions, to evaluate the current layout and to show potential areas for improvement by evaluating different layout alternatives. However, the conception of simulation models and their exploitation is often reserved for specialists in this field.

Therefore, several researchers have applied simulation to FLP under different domains. To solve the facility layout problem, Wang et al. (2008) propose a DES optimization model based on Genetic Algorithm (GA) and simulation. In a first step, GA generates candidate layout schemes to guides the system towards better solutions. Then, Simulation models are used to evaluate the performance of these candidate solutions. Next, the results of evaluation step are returned to the GA to be utilized in selection of the next generation of candidate. This process continues until a satisfactory solution is obtained.

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Jithavech and Krishnan (2010) presented a simulation-based method for predicting the uncertainty associated with the layout design under uncertainty in the product demand to reduce the risk associated with the layout. A GA procedure is used to generate the layouts for both the projected demand case and the risk-based layout design. The simulation approach has been validated by comparing with analytical approaches and tested on several case study.

Hospitals have very strong analogies with other industrial systems. It is interesting to build generic models and locate problems within the class of hospital systems. In this field, Vos et al. (2007) developed an evaluation method for the assessment of hospital building design to provide a valuable tool for the assessment of both functionality and the ability to meet future developments in operational control of a building design. For this, the method is 1) Distinguish segments of the floor plan, 2) Determine flows of persons and goods, 3) Design experiments, 4) Implement the model and 5) Run the simulation model, experiment and analyze the results.

Arnolds et al (2012) presented a framework for hospital layout planning to generate a robust hospital layout plan using DES in combination with mathematical models through a sensitivity analysis of different layout plans in various scenarios with stochastic patient flows. The DES model can easily be adapted to different layout plans by changing the location assignment for the departments.

Gibson (2006) provides a DES model to plan a hospital building that supports delivery of patient care and resource usage. O'Hara et al 2004, provide examples of using discrete-event simulation as a tool in the design of an ambulatory care surgery. Chu, Lin, and Lam (2003) developed a decision support system to evaluate lift performance for existing hospitals and predict it for a new one.

2. PROBLEM STATMENT

The facility layout design of plants in manufacturing systems aims to arrange in an effective layout to minimize the material handling costs. However, the design of OT in hospitals has different objectives beyond classical manufacturing requirements, it aims to find a layout design that reduces operating expenses and the duration of the health care process, enhances the quality of work environment, increases the staff effectiveness, improves patient and staff satisfaction and optimizes the resources utilization.

Given a set of activities, their areas and the available space, the OT Layout Planning (OTLP) seeks to determine the optimal placement of the set of activities within the available space subject to non-overlapping activities on the floor plan layout while optimizing the value of the objective function. To find the optimal placement, a multi-goal Mixed Integer Programming model is proposed to solve the multi-section in the OTLP in Chraibi et al. (2014). The main objectives are minimizing the traveling costs for the considered entities (doctors, patients, medical and non-medical staff) and maximizing the closeness ranking among activities to accommodate health services within the optimally layout of such activities.

The mathematical model contains of non-overlapping constraints, bounds constraints, distance constraints, the use of corridors constraints while respecting international standards in building healthcare facilities (see reference AIA, FGI...). In (1) we present the objective function of the proposed mathematical model:

$$F = \rho_1 \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{4} F_{ijk} D_{ij} (\varphi_{ijk} * \sigma_k) - \rho_2 \sum_{i=1}^{N} \sum_{j=1}^{N} R_{ij} \mu_{ij} \quad (1)$$

Where:

- D_{ij} is the distance between two facilities 'i' and 'j';
- ρ1, ρ2 are weights for each sub-objective function;
- F_{ijk} is the number of trips between facilities 'i' and 'j' made by an entity type 'k';
- φ_{ijk} is the moving difficulty between facilities 'i' and 'j' made by an entity 'k';
- σ_k is the traveling cost factor assigned to an entity 'k';
- R_{ij} is the relationship value expressing the need for proximity;
- μ_{ij} is the adjacency coefficient expressing the nearness of two facilities.

The model was solved to optimal in static environment and gives satisfying results. The challenge now is to evaluate the capacity of this solution to be efficient and effective in responding to fluctuant care demand in different periods of the year. Otherwise, to test the possibilities of restructure the current layout while minimizing the rearrangement costs.

3. METHODOLIGIE

This paper presents a case study on using computer simulation modelling to describe an evaluation method for the assessment of an OT layout. We developed a robust optimization using a simulation approach with an iterative process of assessment and improvement. In the preliminary stage, our Mixed Integer Programming (MIP) model in Chraibi et al. (2014) is solved for the Operating Theater Layout Problem (OTLP) based on deterministic data.