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CASE STUDY

Performance-driven design with the support of digital tools: Applying discrete event simulation and space syntax on the design of the emergency department

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Abstract
Planning the design of the emergency department (ED) is a complex process. Hospital leaders and architects must consider many complex and interdependent factors, including evolving market demands, patient volume, care models, operational processes, staffing, and medical equipment. The application of digital tools, such as discrete event simulation (DES) and space syntax analysis (SSA), allows hospital administrators and designers to quantitatively and objectively optimize their facilities. This paper presents a case study that utilized both DES and SSA to optimize the care process and to design the space in an ED environment. DES was applied in three phases: master planning, process improvement in the existing ED, and designing the new ED. SSA was used to compare the new design with the existing layout to evaluate the effectiveness of the new design in supporting visual surveillance and care coordination.
This case study demonstrates that DES and SSA are effective tools for facilitating decision-making related to design, reducing capital and operational costs, and improving organizational performance. DES focuses on operational processes and care flow. SSA complements DES with its strength in linking space to human behavior. Combining both tools can lead to high-performance ED design and can extend to broad applications in health care.

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1. Introduction

The emergency department (ED) is recognized in the United States (US) as the "front door" of hospitals, through which approximately 68% of all admitted hospital patients pass (Emergency Department Benchmarking Alliance (EDBA, 2013)). The volume of long-term ED admittance increases by 3% per year, according to the 1992 National Hospital Ambulatory Medical Care Survey (NHAMCS), an annual summary published by the Centers for Disease Control and Prevention National Center of Health Statistics (CDC/NCHS). For example, the admittance volume in US EDs from 2008 to 2009 increased from 123.8 million to 136 million patients. Approximately 150 million patients are expected to be admitted in American EDs in 2013 (CDC/NCHS, 2013). US EDs currently face challenges such as crowding and long waiting time because of the large volume of patients and the uncertainty in their arrival pattern. The median length of stay (LOS) of all patients is approximately 169 min, according to the latest EDBA survey (2013), which included 974 EDs across the US. The median LOS of patients who are admitted in hospitals can be as long as 286 min. The median LOS of patients admitted in the Super ED Center, where patient volume reaches over 100,000, is 387 min, that is, longer than 6 h. Such long LOS contributes to high patient walkaway rate or cases of "left before treatment complete" (LBTC), both of which pose risks to patient safety. Figure 1 demonstrates that a direct correlation exists between ED LOS and LBTC, and such correlation generally increases as ED volume increases.

American EDs have been under significant pressure to improve the quality and efficiency of the health care they provide to their patients. Many EDs have considered updating their facilities and improving their processes. The 2010 NHAMCS data show that 23% of the respondent EDs added ED treatment spaces in the last 24 months, whereas 20% planned to expand in the next 24 months.

To ensure an environment that optimizes ED performance, hospital leaders and architects need to make decisions that consider many complex and interdependent factors, including evolving market demands, patient volume, care models, operational processes, staffing, medical equipment, and technology. The application of digital tools, such as discrete event simulation (DES) and space syntax analysis (SSA), allows hospital administrators and designers to quantitatively and objectively optimize their facilities and processes.

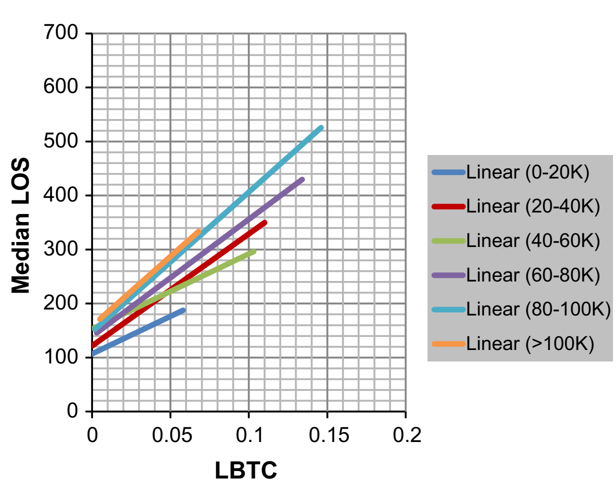

Figure 1 Correlation of median LOS and LBTC of different volume cohort groups (EDBA 2004–2011 data).

1.1. DES in health care

DES is a type of computer-based modeling that imitates the operation of a real-world system (Hamrock et al., 2012). A discrete event should be considered "as occurring instantaneously and causing transitions from one state value to another" (Cassandras and Lafortune, 2008: 27). DES was originally developed in industrial engineering during the 1960lo and was applied to analyze industrial processes. DES models have gained increased popularity over the past 40 years among health care administrators as effective tools for allocating resources, improving patient flow, increasing patient satisfaction, and reducing health care delivery costs (Jacobson et al., 2006; Jun et al., 1999; Karnon et al., 2012). DES is particularly appropriate for health care settings because it is capable of modeling events that trigger both predicable and unpredictable processes and of incorporating variability, which is common in health care systems (Saunders, 2010). Unlike static tools, such as spreadsheets, DES can also model complex interactions within and between departments. It allows decision makers to test various "what-if" scenarios systematically by evaluating the effects of multiple variables and to modify solutions until an optimal scenario is achieved.

1.1.1. Previous applications of DES in health care

DES has been applied in health care in various settings. Many publications have reported the application of DES in process redesign and optimization (Jun et al., 1999), staff scheduling (Alessandra and Grazman, 1978; Draeger, 1992; Rossetti et al., 1999), scheduling patients and procedures in outpatient (Cayirli et al., 2006) and surgical units (Fitzpatrick et al., 1993; Murphy et al., 1985), managing patient admission in inpatient units (Hancock and Walter, 1979; Lim et al., 1975), and using ancillary resources, such as laboratories, pharmacies, and imaging departments (Fone et al., 2003; Jacobson et al., 2006; Mukherjee, 1991). DES has also been proven to be effective in allocating health care assets, such as sizing and capacity planning of facilities (Saunders, 2010), exam rooms (Levy et al., 1989; Mahachek and Knabe, 1984), patient beds (Cohen et al., 1980; Kletke and Dooley, 1984; Zilm, 1980; Zilm and Hollis, 1983), and operating rooms (Kuzdrall et al., 1981), as well as resource allocation for staffing (Klafehn and Owens, 1987) and equipment (Bodtker et al., 1993; Jun et al., 1999; López-Valcárcel and Pérez (1994)).

1.1.2. Application of DES in ED design

The ED is a significant focus of DES applications in health care because of the unpredictable patient arrival and complex patient flow within its environment. Some studies have focused on optimal staff sizing and scheduling (Draeger, 1992; Duguay and Chetouane, 2007; Evans et al., 1996; Klafehn and Owens, 1987; López-Valcárcel and Pérez (1994); Rossetti et al., 1999). Draeger (1992) used DES to test two alternative nursing staffing schedules against an existing schedule and found that patient LOS and waiting time can be reduced solely by changing the nursing staff schedule. Evans et al. (1996) used the simulation model to