

Abstract

Background: Emergency departments (EDs) during pandemics face overcrowding, resource shortages, and increased workflow errors. Simulation approaches provide an effective means to analyze the current situation and evaluate managerial scenarios without disrupting real systems. This study aimed to optimize the performance of Afzalipour Hospital's ED during the COVID-۱۹ peak using agent-based modeling (ABM).

Methods: This exploratory sequential mixed-method study was conducted in two main phases: system analysis, and simulation and optimization. First, a systematic scoping review following the PRISMA-ScR guideline was performed in international and Persian databases to identify key performance indicators (KPIs), which were then classified within the Balanced Scorecard (BSC) framework. For system analysis, field observations and semi-structured interviews with ۴۵ participants (۵ strategic committee members and ۴۰ frontline ED staff including physicians, nurses, and support personnel) were conducted using purposive sampling. Quantitative data were collected through Six Sigma assessments on ۹۰ patients across three shifts, as well as census data extracted from the ED's Hospital Information System (HIS) during August ۲۰۲۱, coinciding with the fifth wave of the COVID-۱۹ pandemic. In the second phase, an agent-based simulation model was developed in AnyLogic PLE version ۸,۹,۵ to represent patient flow from admission to discharge, bed utilization, paraclinical services, and staff workload. Seven optimization scenarios were designed, including increased numbers of beds, consultants, nurses, triage nurses, technicians, and orderlies(porters). These scenarios were prioritized using the Analytic Hierarchy Process (AHP), and their outcomes were compared based on simulation results.

Results: Findings from the literature review revealed that most prior studies focused primarily on time-based indicators, such as length of stay (LOS), while financial, resource utilization, and quality-related KPIs were less frequently considered. Six Sigma analysis of Afzalipour ED processes showed potential for up to ۵۰٪ improvement ($\approx 3\sigma$). Major bottlenecks included the acute unit, triage, and patient transfers to diagnostic units. Key challenges were delays in paraclinical services, shortages of specialist physicians (especially infectious disease specialists), insufficient skilled nurses, and inadequate support staff—particularly during evening and night shifts. Simulation results indicated that Scenario ۲ (increasing the number of orderlies) and Scenario ۳ (increasing medical consultants) performed best in terms of cost-effectiveness, feasibility, resource availability, and reduction of patient LOS. Overall, human resource improvements, especially in supportive and consultative roles, were found to be crucial in reducing patient LOS and enhancing ED efficiency.

Conclusion: Agent-based simulation proved to be a powerful tool for analyzing and optimizing ED performance during critical situations. This approach enabled the identification of bottlenecks and inefficiencies, while also allowing the evaluation of various managerial scenarios prior to implementation. The findings highlight that combined interventions involving human resources, physical infrastructure, and managerial strategies can significantly improve service quality and resource utilization. Applying this approach in other hospitals may serve as a practical strategy to enhance the resilience of healthcare systems against future pandemics.

Keywords: Emergency department, simulation, agent-based modeling, Balanced Scorecard (BSC), Six Sigma , optimization



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