An emergency medical services system design using mathematical modeling and simulation-based optimization approaches

Motivation:

An emergency medical services (EMS) system plays a crucial role in stabilizing and transporting seriously injured patients to hospitals within healthcare systems. Several criteria affect the EMS function, such as call rate, traffic condition, setup, and operating costs. Therefore, the optimal design of EMS systems, including determining the location of emergency medical bases and allocating ambulances, helps improve service performance. On the frontlines of national disasters and health crises, EMS play a crucial role in preventing deaths and injuries. With the shift in community needs as a result of changing lifestyles and increased life expectancy, requests for EMS have been on the rise. The provision of high-quality EMS is expected to be consistently delivered at the national level. Healthcare managers constantly struggle with competing budget demands and staffing challenges, making the delivery of adequate service levels even more difficult. This complexity of EMS systems calls for resource allocation approaches that are capable of optimizing productivity and efficiency.

Contribution:

Although many research studies have been done to assess emergency medical services (EMS) performance, the pertinent literature pays less attention to system cost as a vital assessment factor. A quick EMS response is essential to improving survival rates and EMS performance. This study presents a simulation-based optimization approach based on the maximization of the survival rate and minimization of the total cost. The study contributes to a multifaceted framework that combines a dual-objective optimization model, computer simulation analysis, and practical validation, ultimately enhancing the design and performance of an EMS system with a focus on maximizing survival rate. A case study also presented in this paper for the Emegerncy Management Center in Ifsahan.

Methodology:

In this paper, the objective is to design an EMS system that minimizes the total cost (costs of preparation and construction of stations and purchasing cost of ambulance vehicles) while maximizing the overall expected survival probability of patients. The steps that are followed are :

- Determining the potential locations for an emergency station based upon various factors such as population density and ac- cessibility.

- Defining the demand points. All people living in a city are po- tential demand points. For simplicity's sake, the gravity centers of areas in the city are considered as demand points.
- Estimating traveling time between each station and demand points in the light of various important factors such as the traffic and weather conditions.
- Estimating the costs of buying the ambulances and constructing the emergency stations.
- Solving the proposed model under the static condition to reach the primary solution. This solution is used as a primary input for the computer simulation model in the lower step.
- Applying simulation to analyze the different scenarios which can help consider the real-world conditions in the mathematical model. A range of scenarios can be defined via changing (i) the number of emergency stations, (ii) the allocated ambulances and (iii) the probability of ambulances' availability.
- Using DEA to assess and rank the results of the scenarios ob- tained from simulation in the above step. The scenario with the superior score is the best arrangement (design) for the emergency medical services system.

Conclusion:

This study integrates simulation and optimization techniques to enhance the Emergency Medical Services (EMS) system, aiming to improve survival rates and reduce costs. Recognizing the challenge of incorporating dynamic factors like traffic conditions into mathematical models for EMS analysis, the paper employs simulation methods across various scenarios.The simulation-based optimization model is applied in four selected municipal regions of Isfahan, focusing on designing optimal emergency center locations and allocating ambulances. Six scenarios are defined to simulate the model in dynamic environments, evaluating survival rates and total costs for each scenario. Following this, Data Envelopment Analysis (DEA) is employed to rank scenarios and identify the most effective one. The selected scenarios underscore the significance of considering patient types I and II in EMS facility design to enhance survival rates. This finding emphasizes the importance of tailoring EMS configurations to specific patient needs, thereby contributing to improved overall survival rates.

Future Work:

The suggested method can be expanded for further study by taking into account a few other important variables, such as how the weather and seasonal changes effect ambulance journey times. This approach might be investigated in conjunction with ongoing research on locating predicted emergency situations using methods like artificial neural networks and location-allocation decision models, given the expanding applicability of machine learning techniques. Applying the approach described in this paper to comparable issues in other emergency response systems, including urban firefighting facilities systems, may also prove to be a valuable research project.