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Simulating changes to emergency care resources to compare system effectiveness

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Abstract

Objective: To apply systems optimization methods to simulate and compare the most effective locations for emergency care resources as measured by access to care.

Study Design and Setting: This study was an optimization analysis of the locations of trauma centers (TCs), helicopter depots (HDs), and severely injured patients in need of time-critical care in select US states. Access was defined as the percentage of injured patients who could reach a level I/II TC within 45 or 60 minutes. Optimal locations were determined by a search algorithm that considered all candidate sites within a set of existing hospitals and airports in finding the best solutions that maximized access.

Results: Across a dozen states, existing access to TCs within 60 minutes ranged from 31.1% to 95.6%, with a mean of 71.5%. Access increased from 0.8% to 35.0% after optimal addition of one or two TCs. Access increased from 1.0% to 15.3% after optimal addition of one or two HDs. Relocation of TCs and HDs (optimal removal followed by optimal addition) produced similar results.

Conclusions: Optimal changes to TCs produced greater increases in access to care than optimal changes to HDs although these results varied across states. Systems optimization methods can be used to compare the impacts of different resource configurations and their possible effects on access to care. These methods to determine optimal resource allocation can be applied to many domains, including comparative effectiveness and patient-centered outcomes research.

Keywords: Health system optimization; Access to care; Geography; Health policy; Trauma center; Wound and injuries; Location science

1. Introduction

Epidemiology, as a field, has its origins in analytic geographic methods, most famously in the form of the John Snow narrative of water pumps and cholera in London [1]. Clinical epidemiology, as a chapter in the broader field of epidemiology, is generally defined as the study of illness in persons seen by providers of medical care [2]. It is here where the value of the work conducted in this article converges on the novel approach of using spatial epidemiologic methods for analytic research in clinical epidemiology.

Spatial epidemiologic methods for analytic purposes have matured over the past half century, outpacing standard geographic information system (GIS) approaches which remain, for the most part, descriptive methods to visually explore maps of health phenomena. These GIS methods, although valuable, are generally not used to directly analyze the impacts of changes to the locations of various phenomena in space. Although geographic variation in health care has been visually documented for decades and is a good example of descriptive GIS work, this line of research offers little in terms of direct analyses or counterfactuals, that is, what might happen if the health care system itself were spatially altered [3,4].

The work presented here takes this next step as a form of comparative effectiveness research (CER) focusing on geographic changes to population-wide health care delivery

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What is new?

- Emergency care system design has the potential to be meaningfully assisted by quantitative simulation techniques that compare the effects of different resource configurations.
- Trauma center (TC) and helicopter depot (HD) locations determine whether severely injured patients can rapidly access TC care and, in many cases, survive their injuries.
- Increases in access to trauma care following the optimal addition of TCs or HDs can be large, potentially affecting substantial populations, although these increases can also vary widely among states.
- Operations research and mathematical optimization techniques can be used in the siting of emergency care resources, potentially improving access to care and system effectiveness for time-sensitive diseases such as trauma and stroke.
- The methods described here can be applied to resource allocation questions in many domains, including comparative effectiveness research and patient-centered outcomes research.

systems which, according to the Institute of Medicine, is a primary focus of its CER portfolio [5]. In fact, work akin to this system-wide CER has already been occurring for decades in operations research and topothesiology, although this work has largely emerged from schools of engineering and applied sciences with little notice from CER, thought leaders in health care and medicine [6]. This article partly aims to change this by specifically using the systems of trauma centers (TCs) and ambulances in multiple states as illustrative examples of the general value of this approach.

Trauma is a major cause of disability, mortality, and health care use in the United States, resulting in millions of emergency department (ED) visits and hospitalizations and hundreds of thousands of deaths each year [1]. Prior studies [7,8] have shown that TC care and medical helicopter transport of severely injured patients can reduce mortality by 25% and 15%, respectively. Because trauma is such a time-sensitive disease condition, rapid access to TC care is also a major driver of survival outcomes for severely injured patients and also consequently for system effectiveness. However, about 10% of the total US population cannot access TC care within 60 minutes, and in some states, this figure is as high as two-thirds or more of the population [9]. Thus, one of the Department of Health and Human Services' Healthy People 2020 benchmark goals is to increase access to TC care over the next several years [10].

Improving access to TC care is a challenge for health planners. The time-critical and unplanned nature of severe injury necessitates system design from the perspective of the population, as trauma can affect anyone at almost any time with little, if any, warning. Trauma patients can almost never anticipate the onset of their illness and therefore rely on the emergency care system to ensure that they receive high-quality health services in a timely manner following an unplanned injury. In this context, the national emergency care safety net requires a system to ensure that the injured patients quickly receive the care they need when their own decision-making capabilities are limited by the unexpected rapid onset of severe and often life-threatening conditions.

In time-sensitive conditions such as trauma, well-planned geographic access to emergency care therefore becomes vital, as it affects time to treatment, survival, and overall system effectiveness. For decades, trauma care systems have been developed to deliver trauma patients to facilities capable of providing them with optimal in-hospital treatment, but these systems have not always used evidence-based rationales for the strategic placement of resources, such as TCs and medical helicopters. The expense of maintaining these facilities [11] supports the need for a system that locates these resources in a way that maximizes rapid access to care and, by extension, patient survival. Our first goal in this study was to apply systems optimization methods to determine the best initial locations, and relocations, for additional trauma care resources in select US states. Our second goal was to then compare these simulated changes with the existing state systems in terms of access to care, a process outcome of system effectiveness for time-sensitive conditions such as severe trauma.

2. Methods

2.1. Study design and data

This study was an optimization analysis of the locations of TCs, helicopter depots (HDs), and severely injured patients in a dozen states; optimal TC locations were calculated so as to maximize the number of severely trauma patients who would be able to access them in less than 60 minutes. As with prior work [12,13], the objective function of the optimization models here was to maximize 60-minute access to TCs for severely injured patients using constraints related to the locations of existing and candidate TCs and HDs, ground and air travel networks, and the number of new TCs or HDs that were to be optimally located.

The states included were Colorado, Florida, Iowa, Maryland, New Jersey, New York, North Carolina, Oklahoma, Oregon, Pennsylvania, Utah, and Washington. These 12 states were selected based on the availability of ZIP code–level hospital discharge data, although they are also reasonably representative in terms of topography (both land area and elevation), demography, and health care systems.

Candidate sites for TCs were acute care hospitals with 24/7 EDs, and candidate sites for HDs were all existing civilian airports, TCs, or acute care hospitals that could