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Aeromedical retrieval of trauma patients: Impact of flight path model on estimates of population coverage

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ABSTRACT

Background: The aim of this study was to compare the impact of different flight path models on the calculated population coverage of aeromedical retrieval systems, using the state of Alabama as a case study.

Methods: Geospatial analysis of U.S. Census Bureau population data using helicopter bases and trauma centers as foci of either circular or elliptical coverage areas.

Results: Circular isochrone models around helicopter bases or trauma centers suggest that the entire population of Alabama could reach a level I or II trauma center within 60 min. Elliptical isochrones, incorporating outbound and inbound flights, suggest that only 78.8% of the population have ready access to level I or II trauma centers.

Conclusion: While all three flight path models described have some validity and utility, simplistic circular flight time isochrones around trauma centers and helicopter bases provide overly optimistic estimates of population coverage. The elliptical model provides a more realistic evaluation.

Introduction

Trauma is a time-critical condition, and trauma systems – managed clinical networks of trauma centers and Emergency Medical Services (EMS) – have been shown to reduce mortality and disability from injury.[1] The aim of a trauma system is to deliver the patient directly to a facility where "definitive care" can be delivered, whenever possible.[2] Most trauma systems use an access time threshold, typically set at 60 min, which determines whether a patient can be taken directly to the desired level of care as determined by prehospital triage,[3] or has to be taken to another facility first and then transferred secondarily.[2] Accessibility is therefore often measured in terms of "population coverage", which is the number or proportion of residents who can be reached within this set time, or who can reach a trauma center within 60 min.

Because of their faster speeds, helicopters are often seen as a key means to improving access to specialist trauma care – by doctors, administrators, politicians, and the public.[4] However, the logistics of helicopter transport are often misunderstood, and the reporting of population coverage provided by helicopters is a prime example. In many trauma systems, helicopters are not based at trauma centers. Furthermore, helicopters are often only called once the patient has been assessed by a ground-based EMS unit. As a result, there are at least three different methods of estimating population coverage: firstly, the population that can be reached within 60 min from the helicopters' base locations; secondly, the population that can reach a trauma center within the 60 min access time threshold on a one-way flight; and thirdly, the population that can reach a trauma center, considering both the flight to the incident location and the flight from the scene to the trauma center. The aim of this study was to illustrate and highlight the differences between these metrics, using the state of Alabama as a case study.

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Methods

Design and data sources

This a geospatial analysis of population coverage. "Coverage" was defined as the proportion of the population within reach of a helicopter in a set time, or within the area from which a casualty could be taken to a trauma center in a set time. The analyses were conducted using georeferenced U.S. Census Bureau population data. The locations of helicopter bases and level I and II trauma centers were obtained using open internet searches. All locations were geocoded into longitude and latitude using Google Maps. The data were collated in a Microsoft® Excel (Microsoft, Redwood, California) spreadsheet. This study was approved by the Institutional Review Board of the University of Alabama at Birmingham (reference #300003526).

Setting

Alabama has a land area of 52,419 mi^2 (135,765 km^2), and a population of 4,779,736. The population density ranges from 12.5 residents/mi^2 to 586.2 residents/mi^2,[5] reflecting the state's mixed urban/rural population distribution. In 2018, the state had three level I trauma centers (in Birmingham, Mobile, and Huntsville), and two level II trauma centers (in Montgomery and Dothan) (Fig. 1). There were 13 helicopters, based in Cusseta, Rainbow City, Sylacauga, Meridianville, Dothan, Troy, Wetumpka, Tuscumbia, Vinemont, Scottsboro, Demopolis, Fayette, and Stapleton. We assumed that helicopters were able to land at the scene of an incident, and that ground transport to a landing zone was not required. We used individual airframes' published cruising speeds to calculate distances travelled.

Derivation of coverage areas

An isochrone is an area which can be reached from a central location within a set time, or from which a central location can be reached. Therefore, the borders of the following flight coverage areas are dictated by the access time threshold, defined as the maximum duration within which a patient can reach a desired level of care; the helicopter's cruising speed, and – where applicable – time spent on the ground. As per our aims, we calculated three different types of coverage data:

The area/population that can be reached, within 60 min, from the helicopters' base locations. This was calculated by creating circular areas around the helicopters' base locations, representing the area (and, by inference, population) that a helicopter could reach within 60 min. The radii of these circles represented the distance which the helicopter could fly in 60 min. Fig. 2 shows a typical air medical provider's website, highlighting how these circular flight-time isochrones are used to illustrate coverage.

The area/population that can reach a trauma center within the 60-min access time threshold. This was calculated by creating circular areas around the trauma center locations, representing the area (and, by inference, population) from which casualties could be taken to a trauma center, within 60 min. The radii of these circles represented the distance which the helicopter could fly, one-way, in 60 min.

The area/population that can reach a trauma center, considering the flight to the incident location, mission ground time, and the flight from the scene to the trauma center. These areas are described by an ellipse-shaped isochrone, defined by the flight segments. The first segment is from the helicopter's base location to the scene, and the second from the scene to the trauma center. The ellipse's foci are the location of the helicopter base and the trauma center, and whose radii can be calculated from the helicopter's cruising speed and the access time threshold. This methodology has been used previously, and described in detail.[6,7] In short, the areas were calculated using Microsoft® Excel and arcGIS™. The distance between trauma centers and helicopter bases was calculated using the spherical law of cosines. Bearing and midpoint between coordinates were calculated using a rhumb line (a line of constant bearing) approach.[8,9] The major and minor radius of the ellipse were then calculated using a standard approach – the major radius was the maximum distance that could be travelled by the helicopter in the available flying time, and the minor radius was calculated using Cartesian geometry.[10] We assumed 30 min of "mission ground time" – the time between landing at the incident location, loading the casualty into the aircraft, and taking off again.

Spatial analysis

Population coverage was calculated by overlying the coverage areas onto population distribution maps, which are freely available. The U.S. Census Bureau reports the number of residents per census block, and this information is available as "shapefiles", the standard file format for geographical analysis. The analysis was conducted using arcGIS™ (ESRI, Redlands, CA). The results are presented as maps.

Results

Model 1: Circular isochrones around helicopters' base locations

This model describes the area and population that can be reached, within 60 min, from the helicopters' base locations. As there are 13 helicopter locations, 13 circular isochrones were created, surrounding each of the bases. These circular isochrones are shown cartographically in Fig. 3. When combined, these isochrones included 100% of the state's population, or 4,779,736 residents.

Model 2: Circular isochrones around trauma centers

Model 2 describes the area and population that can reach a level I or level II trauma center within 60 min (Fig. 4). There are five such centers, and five corresponding isochrones. When combined, these isochrones also included 100% of the population, or 4,779,736 residents.

Model 3: Elliptical isochrones around helicopter base locations and trauma centers

This model produced 17 elliptical isochrones that included both a helicopter base and a level I or II trauma center, reachable within 60 min, as shown in Fig. 5. When combined, these ellipses included 3,764,368 residents, or 78.8% of the total population of the state.

Discussion

Access to healthcare is an important issue. Specialist services, such as trauma care, cannot be provided in all locations. Geographical access may be limited either by distance or terrain, and is therefore inherently inequitable.[11] Helicopters are a means of reducing this inequity, but comparing and developing systems of care requires a method of analyzing accessibility.

The evaluation of aeromedical retrieval systems requires certain assumptions regarding how the aircraft are tasked. The key metric for evaluating trauma center access is the time that it takes for the casualty to reach the desired level of care. While the time required

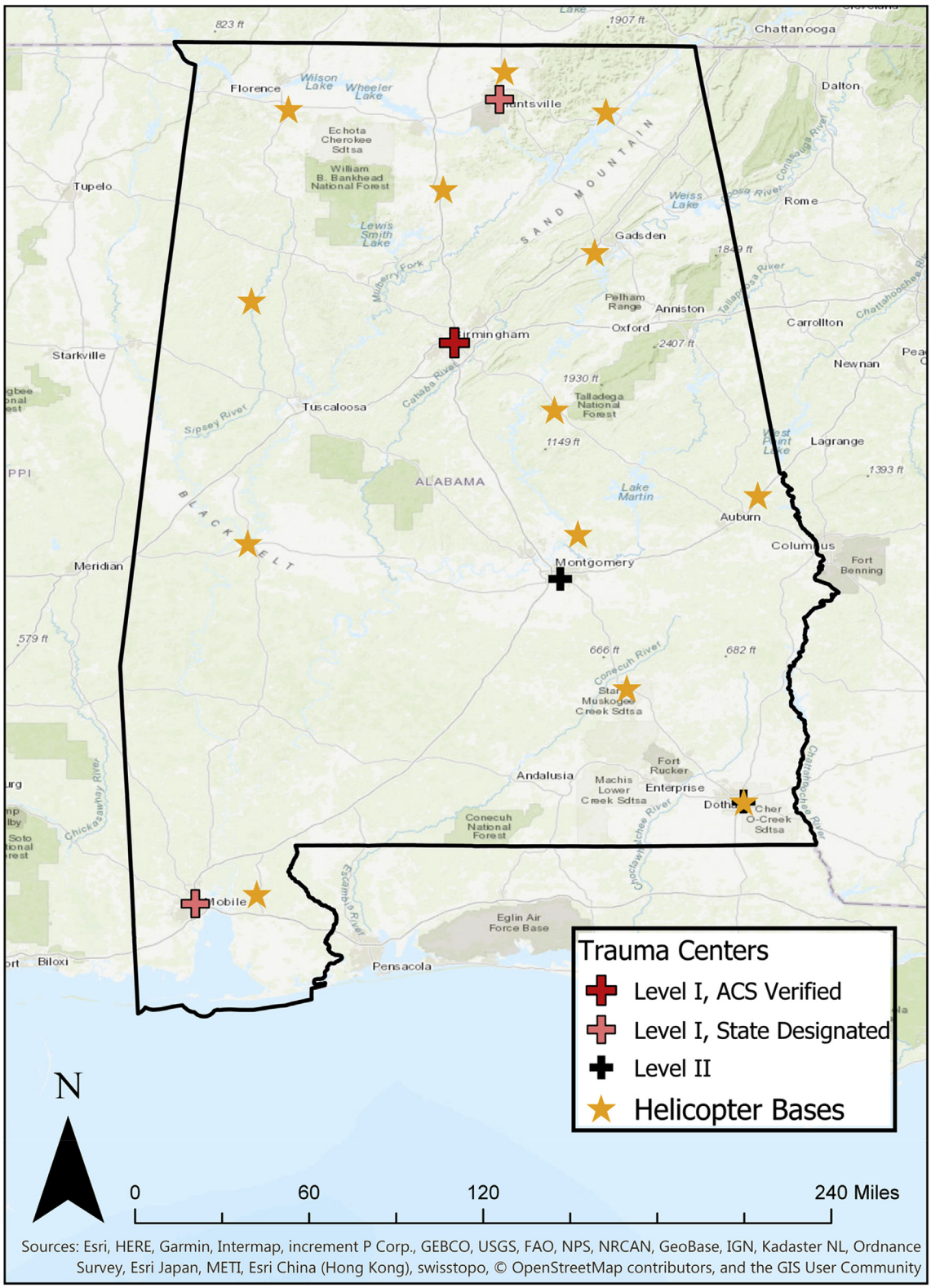

Fig. 1. Map of Alabama's trauma system, showing locations of level I and II trauma centers, and helicopter locations.

for EMS providers to reach the incident location is also important, it is usually much shorter because there are a larger number of EMS ground units, and because they are widely distributed and cover smaller areas, to provide good population coverage. As a result, local EMS ground units can usually reach casualties within minutes of being notified of an incident. Even in rural locations, local ground ambulances can often reach casualties more quickly than a helicopter can. The critical issue therefore becomes the "inbound leg" of the journey, to the trauma center, which may be some distance from the incident location.

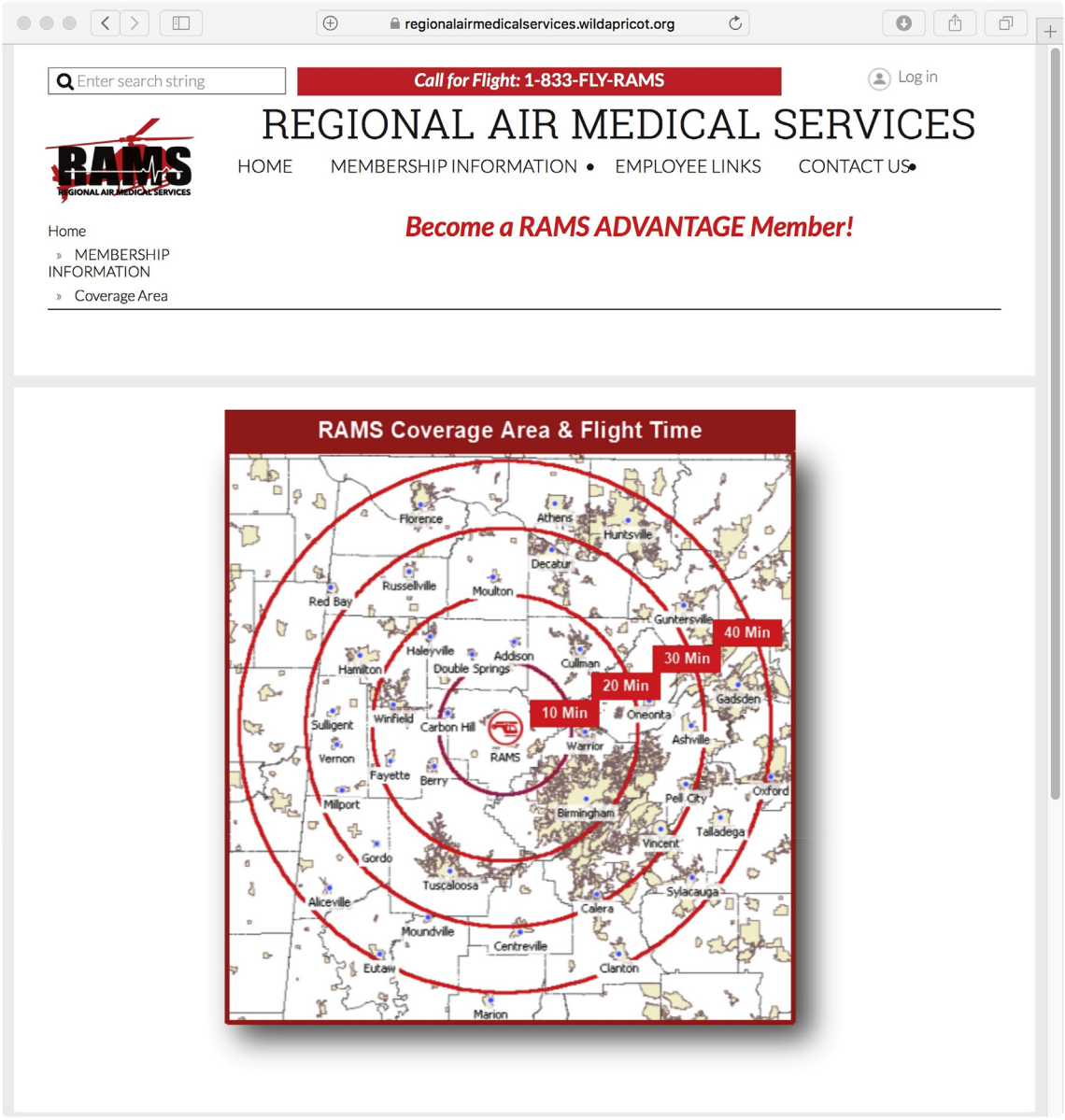

Fig. 2. Typical air medical service provider's website, showing circular isochrones around helicopter base location.

The 100% population coverage calculated from circular isochrones around helicopter base locations (Figs. 1 and 3) is thus falsely reassuring, because these isochrones are not directly relevant to the inbound transport of patients to trauma centers. Furthermore, the much larger coverage areas are even more deceiving due to lack of mission ground time inclusion in coverage calculations. Even when considering the outbound time to reach a casualty, these isochrones are only pertinent in very remote locations, when a ground EMS unit cannot reach a casualty in reasonable time and the helicopter crew will be the first on scene. (However, it could be argued that, in this particular instance, earlier attendance by the helicopter crew would also facilitate earlier transport to the trauma center.) In all other locations, with nearby EMS ground units attending patients first, outbound travel times are short, and it is difficult for helicopters to compete with ambulances. The criteria for entry into the State's trauma system are clearly defined, and all transport (ground and air) is coordinated by the Alabama Trauma Communication Center (TCC). Decisions regarding aeromedical retrieval are made jointly by EMS personnel on the ground, and TCC staff.[12] There are no automatic indications for helicopter retrieval, which could help to shorten retrieval times.

The 100% population coverage associated with circular isochrones around trauma centers is also falsely reassuring, because the time that it takes helicopters to reach the casualty in the first place is neglected. When an incident is attended by a ground EMS crew, who then call for a helicopter, that patient then has to wait for the helicopter to fly out to the scene first (with certain caveats, see below). The third model is therefore the most realistic, because it considers the outbound flight, the time spent at the scene, and the inbound flight. Adjusting for true flight paths and mission ground time, only 78.8% of Alabama's residents could be taken to a level I or II trauma center within 60 min by helicopter, leaving 1 in 5 residents beyond the 60-min access time threshold. This disparity is the consequence of the geographical distribution of the population, the helicopter bases, and the trauma center locations.

Our results show how the tasking of ground and air EMS assets,

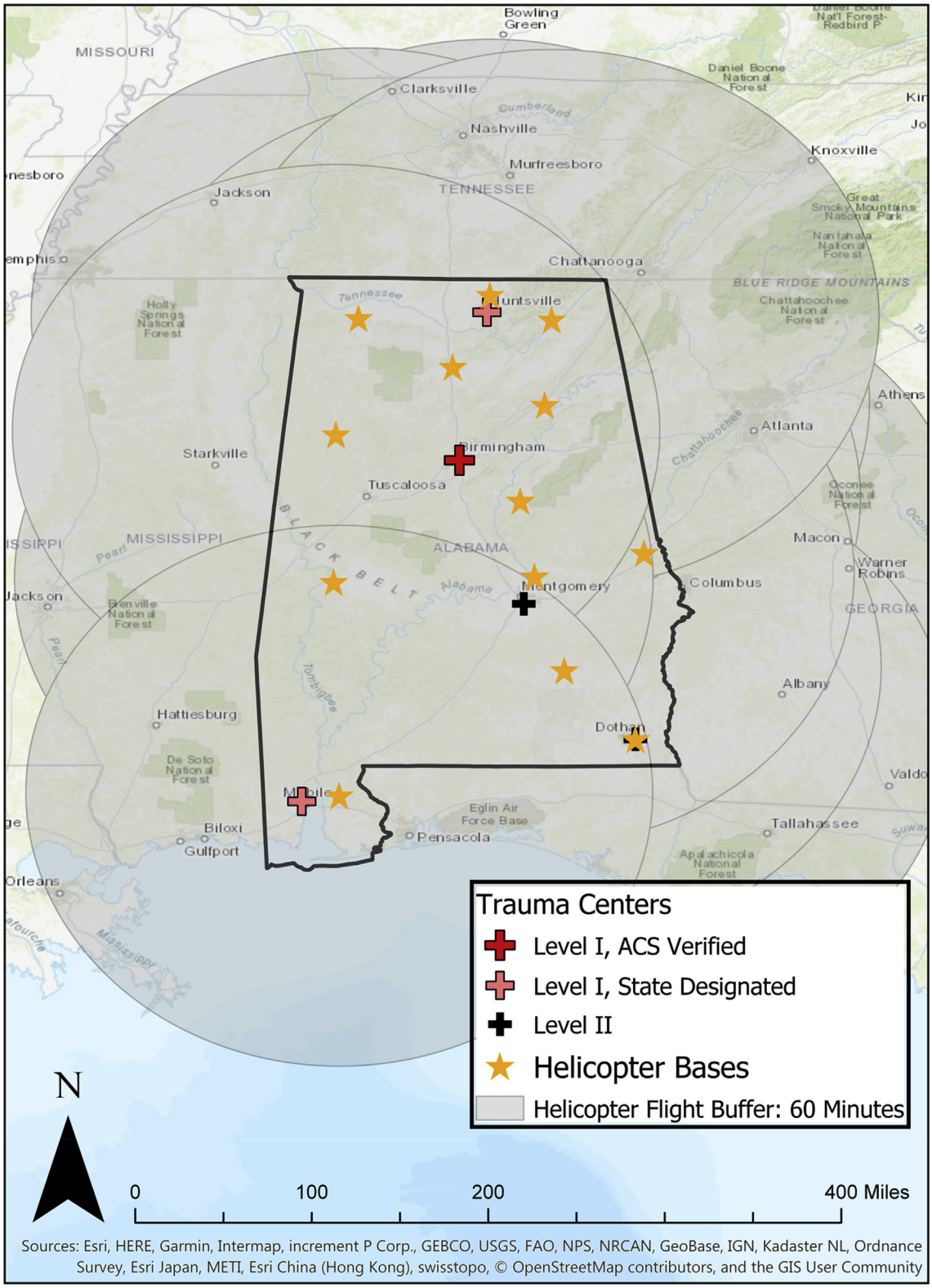

Fig. 3. Map of flight path model 1 - circular isochrones around helicopter base locations.

and the flight path modelling of helicopters, impacts the calculation of areas that can be reached, retrieved from, or both. The configurations of aeromedical retrieval systems frequently change – aircraft are added or removed, or moved to alternative locations. Comparing these different configurations, and their impact on population coverage, is difficult unless the reporting is harmonized. While all three flight path models described here have some validity and utility, the third model is probably the most informative. Although automatic helicopter activation is available in some locations (in which case circular isochrones around base locations

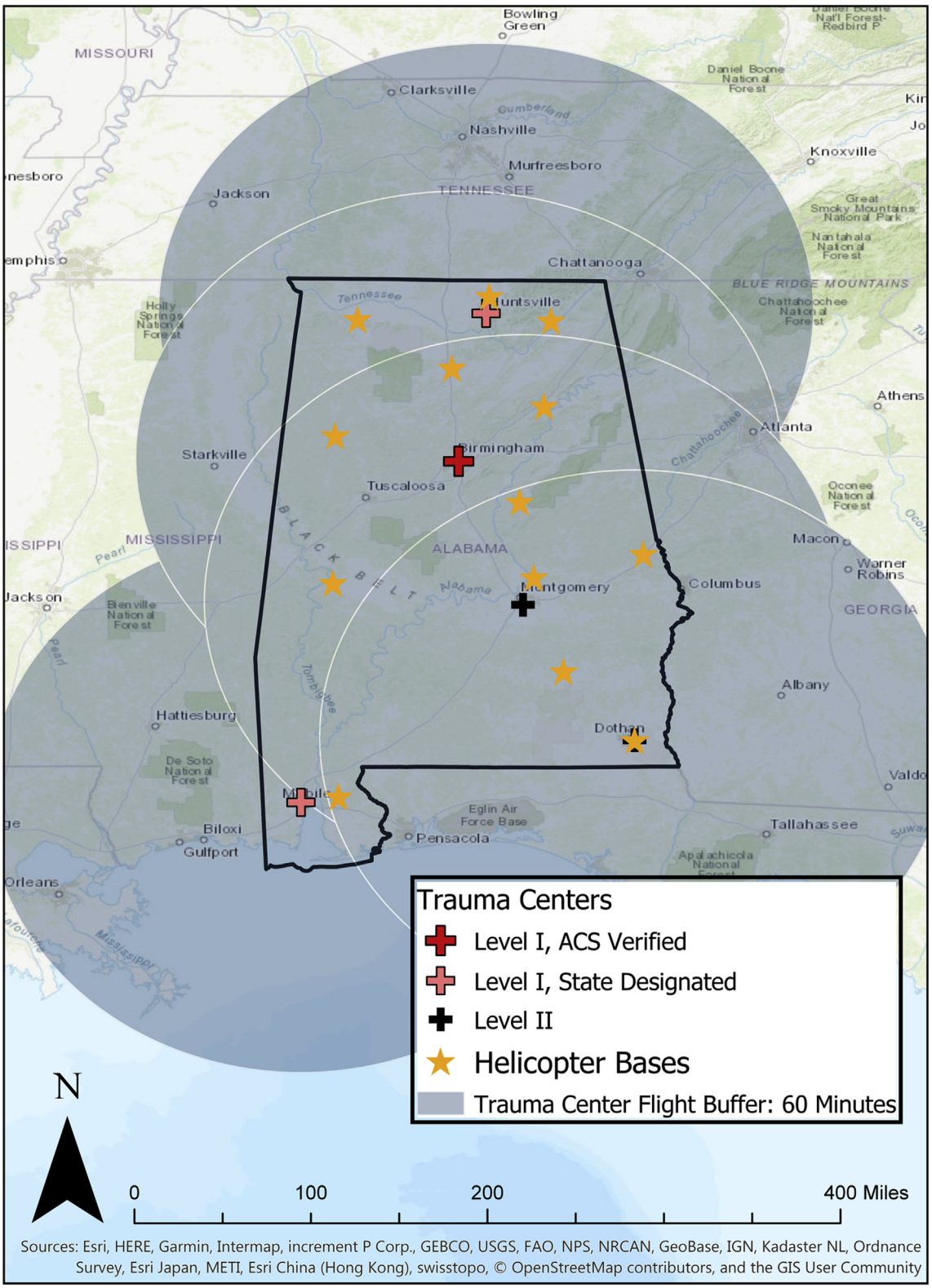

Fig. 4. Map of flight path model 2 - circular isochrones around trauma centers.

and trauma centers become relevant), in most instances, helicopters are only called once ground EMS units have attended the scene. A model which incorporates the outbound flight time, time on the ground, and inbound flight time is therefore the most appealing, and studies from other settings have come to similar conclusions.[6,7]

This study has a number of limitations. It has already been pointed out that the configurations of aeromedical retrieval systems frequently change. Following the completion of this study, three helicopters were removed from the Alabama system, highlighting the need for metrics that can be used to quantify the

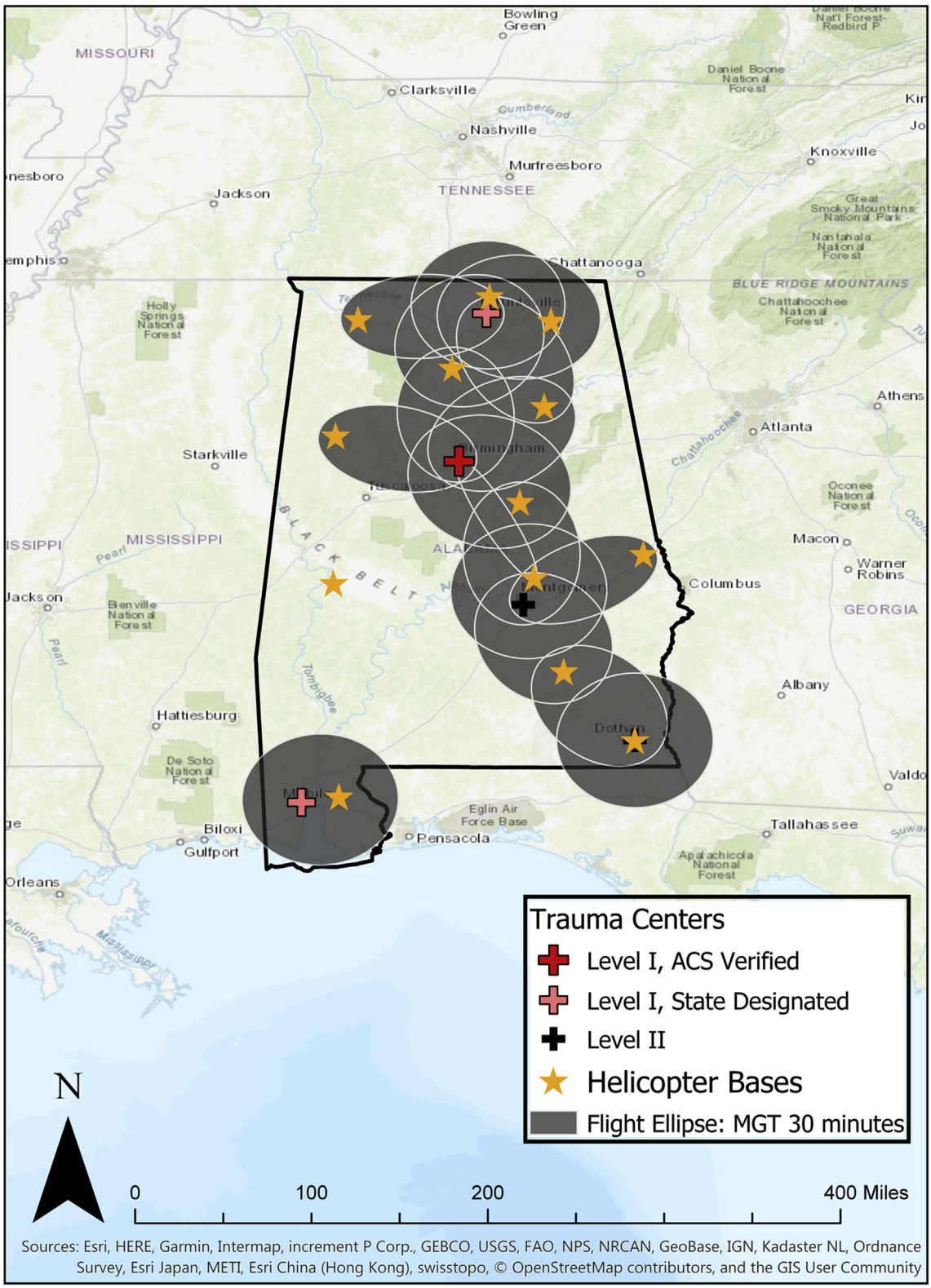

Fig. 5. Map of flight path model 3 - elliptical isochrones around pairs of helicopter base locations and trauma centers.

impact of configuration changes. Additionally, there are hospitals in other states near the Alabama border that are members of the system but were excluded from the study.[12] While coverage areas can be used to inform "siting studies", to decide where helicopters should be based, this is beyond the scope of this present study.

The tasking models described, while conceptually sound, only approximate real-life: ground units and helicopters may be dispatched simultaneously, and may rendezvous en route. Similarly, sometimes helicopters may be called while the casualty is still being extracted from a vehicle. The complexity of such missions is

difficult to model mathematically. We have conducted further analysis of the impact of different mission ground times, which will be reported separately.

Furthermore, helicopters cannot land in all locations, at all times, and do not always fly at the same speed. We used the actual helicopters' cruising speeds, adding to the fidelity of our models. However, the cruising speeds of most commonly used EMS helicopters are similar, yielding similarly-sized isochrones. Weather patterns and instrument flight rules (IFR) versus visual flight rules (VFR) aircraft configurations were not analyzed. (Some EMS helicopters are equipped only to fly under VFR conditions.)[4] Creating a dynamic model of population coverage based on weather patterns is extremely complex, and we therefore assumed flyable weather conditions for all our models. The coverage estimates therefore relate primarily to daytime, and weather conditions which permit flying. Similarly, we did not consider how different providers' policies affect population coverage.

Lastly, the results only apply to trauma patients, though helicopters are also used to transport patients who have suffered life-threatening illnesses.

Despite these limitations, our study adds to the literature on trauma and aeromedical retrieval systems. EMS providers, air medical operators, clinicians, and trauma system administrators should be aware of the different ways in which population coverage can be calculated, and how the choice of flight path model impacts such calculations.

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Declaration of competing interest

Dr. Kerby is the medical director of an EMS agency in Alabama.

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