Analyzing and Optimizing AED Placement Locations in Big Cites —A Geographical Information System Analysis

Yuxuan Shi
Central University of Finance and Economics
gloriashi@126.com

Tianmei Wang
Central University of Finance and Economics
wangtianmei@cufe.edu.cn

Abstract

Out-of-Hospital Cardiac Arrest (OHCA) has been identified as a significant public health issue in China. Numerous studies have demonstrated that using automated external defibrillators (AEDs) can significantly improve the survival rate of OHCA patients, but their low utilization rate is partly due to the accessibility of AED deployment sites.

This study collects the location information of AED devices in three representative cities in China: Beijing, Shanghai, and Shenzhen and then combines the kilometer population grid data (2021) with the AED geographic location data for visualization and data analysis through QGIS and Kepler.GL. Our model considers population distribution, subway, and road traffic factors and proposes a new method for AED index measurement. Through empirical analysis, we discovered that the existing AED distribution has an issue with unequal resource allocation. Thus, we have proposed specific suggestions on quantity and specific zones for AED deployment.

Furthermore, this study proposes three specific suggestions for the problems currently in developing AEDs in China.

Keywords: AED (Automated External Defibrillator), GIS (Geographic Information System), OHCA (Out-of-Hospital Cardiac Arrest)

1. Introduction

OHCA is China's most lethal cardiovascular disease, with a resuscitation success rate of no more than 1%. According to the *China Cardiovascular Disease Report 2021* published by the China Cardiovascular Center [29], the incidence of sudden cardiac death in China is 41.8 per 100,000 people, which is at an intermediate level compared with other countries. However, given the large population, the total number of sudden cardiac deaths in China is as high as 550,000 cases per year, which is equivalent to approximately 1500 people passing away because of cardiac arrest every day. This figure is the highest in the world. The situation is grave and pessimistic.

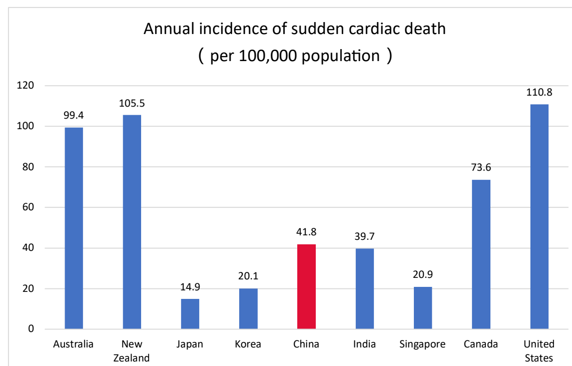

Figure 1. Annual incidence of sudden cardiac death (per 100,000 population)

Types of cardiac arrest include ventricular fibrillation, pulseless electrical activity, and ventricular arrest, with ventricular fibrillation (VF) being the most common (71%) and referring to uncoordinated and chaotic fibrillation of the ventricular muscles with no blood displacement from the heart and loss of heart sounds and pulses, resulting in an immediate cessation of systemic circulation that can be fatal in 3–5 minutes.

According to a medical study, the survival rate reduces by 7–10 percent for every minute of delay in defibrillation [3]. If defibrillation is performed within 1 minute of cardiac arrest, the patient's survival rate can be as high as 90 percent. If effective defibrillation is performed within 4 minutes, the resuscitation success rate can be as high as 60 percent. After 5, 7, 9–11, and more than 12 minutes, it drops to 50, 30, 10, and 2–5 percent, respectively. Beyond 5 minutes, defibrillation causes irreparable brain damage [18].

The automated external defibrillator (AED) is a portable medical device that analyzes particular arrhythmias and administers defibrillation shocks. AEDs are the most successful medical device for out-of-hospital cardiac arrest resuscitation.

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Figure 2. Using an AED

Numerous studies have demonstrated that using AEDs can significantly improve the survival rate of OHCA patients. A study of 13,769 OHCA patients [4] revealed that survival rates were 9.4% with a rescue call and 16.6% with cardiopulmonary resuscitation (CPR) alone but increased to 53.5% with the use of AEDs for shock treatment.

In recent years, China has begun to plan to deploy AED devices, drawing on the experience of developed nations, such as Japan, the United States, and Singapore. Academic organizations, including the China AED Alliance, the Chinese Red Cross Society, and the Emergency Medicine Branch of the Chinese Medical Association, have proposed the Expert Consensus on AED Layout and Deployment in China [17], which provides recommendations and suggestions on the number of AEDs to be deployed, layout, and location of keets. The number of AEDs in public spaces should be set using the standard of 100–200 AEDs per 100,000 people. As representatives of the provinces and cities, Beijing, Shanghai, and Shenzhen have also responded positively and implemented policies to support AED configuration.

However, the late start of policy planning and the high cost of AEDs are subject to financial budget constraints. Thus, only a limited number of AEDs can be placed in a specific geographical area. China's AED per capita allocation rate is only 2.7% per 100,000 people, which is significantly lower than the international average. The graph below uses logarithmic axes for ease of display.

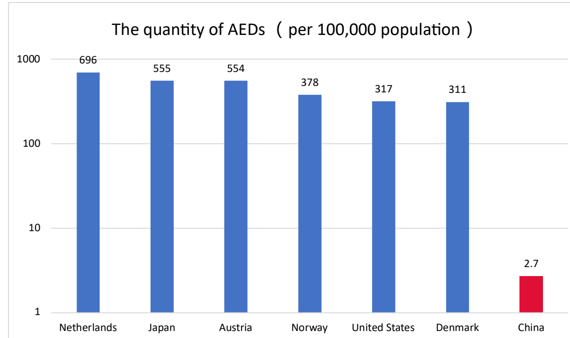

Figure 3. Quantity of AEDs

Currently, the number of AEDs in China is inadequate, and the average arrival time of ambulances cannot satisfy the emergency demand. The key to successful resuscitation for OHCA patients is the correct placement of AEDs [21]. Specifically, medical and transportation resources are scarcer during the COVID-19 crisis, when the OHCA-related death rate continuously climbs. Therefore, the placement of existing AEDs must be optimized and improved.

Furthermore, given the small number of AED manufacturers in China and the different policy planning of individual cities, no unified platform can provide complete and accurate AED information. Thus, people cannot quickly locate the nearest AED when they need one, which may affect the optimal emergency response time.

How to improve the AED coverage and utilization rate with a limited number of AEDs while establishing a unified and comprehensive AED distribution map to create convenient conditions for patients to query information and developing an effective and optimal AED allocation strategy following the characteristics of China's population distribution is a question that must be actively investigated.

Quantitative studies on AED configuration based on GIS and spatial population perspective are lacking, and the indicator directly reflects the reasonable degree of AED deployment. The current index measurement of AEDs is the number of AEDs deployed per capita (per 100,000). This index does not reflect the number of effective AED deployments and does not account for geographic dispersion and population density.

The structure of the paper is as follows:

Sections I and II define the study context, the significance of the research, the research questions, the literature review, and an overview from the standpoint of the discipline.

Sections III and IV describe the data, the analysis procedure, and the created model.

Section V studies the diverse distribution features of the three cities and analyzes the difficulties of the existing AED layout by combining each city's real situation and policy planning.

In the final section of the paper, we present our proposals on the aforementioned issues.

2. Background

The majority of current academic research on AED resource allocation focuses on public policy, healthcare, GIS, and mathematics (i.e., maximizing the allocation strategy of AED resources based on cost-effectiveness, distribution path, and spatial distribution).

Based on the various disciplinary foundations and views upon which the studies are founded, they can be roughly summarized as follows:

First, among the studies that applied the fieldwork method to optimize AED deployment [5], one study [8] conducted fieldwork on the landmark, availability, and equipment situation of AED locations in Yangpu District, Shanghai and found that the number of accessible AEDs was low, the buildings in front of which AED equipment was located lacked visible signage, and a problem with low AED deployment efficiency was found. Another study [13] analyzed all publicly accessible AED rosters in Canada by categorizing each AED location type as completely inaccessible, moderately inaccessible, or accessible. Using location and population mobility data from the *Google COVID-19 Community Mobility Report*, it was determined that the level of foot traffic and AED accessibility in parks and other sites varied significantly.

Given that some regions have not implemented a uniform AED device management system and AED maps, the public is unaware of the precise placement of AEDs, making investigating AED accessibility in the field necessary.

Furthermore, in studies that optimized AED deployment based on cost-benefit, certain studies [10] assessed the costs and benefits of AED deployment in various public venues in Ireland and Sweden. The study revealed that, when OHCA happened in public settings, the use of AEDs would increase by 40 percent, making the program financially viable. Another study [6] demonstrated that placing AEDs in regions with a large concentration of potential patients and rescuers would greatly enhance cost-effectiveness.

Therefore, efficient AED deployment planning will increase patient survival rates and reduce input costs and increase returns, enabling the deployment of AEDs to maximize input and output despite resource limits [28].

Lastly, research on the application of GIS technology for optimizing AED resource allocation is more robust [7], and the following reference indicators are primarily employed as the subject of AED spatial layout [9].

The study of optimizing AED deployment based on the site of cardiac arrest data from Maryland, United States [12] revealed a weak correlation between the location of cardiac arrest and AEDs. Another study [14] used actual data of out-of-hospital cardiac arrest (OHCA) in Baoan District, Shenzhen, China, as the foundation for investigating AED configuration optimization methodologies. One study refined the configuration strategy using historical OHCA data and devised a risk-based method to generate an artificial OHCA layout using a risk model.

AEDs are emergency equipment set up to aid OHCA and should ensure that patients receive AEDs as quickly as possible when OHCA occurs. Thus, optimizing AED deployment based on historical information, such as the location and frequency of OHCA occurrence, is data-supported and rational.

In a study [15] that improved AED deployment from a distribution perspective, a mathematical optimization model was utilized to construct a drone deployment network for North Carolina by specifying the number of sites and goal AED arrival times to pick drone sites for retrofitting from existing AECs. Another study [24] evaluated the prevalence of OHCA and the arrival time of AEDs in each region of Sweden between 2010 and 2018 using a geographical information system perspective and calculated the number of drones required to deliver AEDs to all OHCA instances in under eight minutes.

Recently, with the maturation of drone technology and the rise in public demand for drone delivery, the current market has become a reproducible application scenario in recent years. Although drones have not yet been employed extensively in the field of AED delivery, prompt AED delivery by drones has saved the lives of some patients. Combining the deployment of developing technologies and AEDs has become a future trend.

Less research has been conducted on the quantitative evaluation and optimization of AED deployment from a population-spatial perspective. One study [22] assessed the location of OHCA in China from 2016 to 2019 using the Ustain model and found that 72.36 percent of OHCA happened in the home and a high association existed between the prevalence of OHCA and population growth.

This study determined that, during COVID-19, many governments and businesses encouraged "online" home office and learning mode, population movement was low, and traffic in public locations was severely reduced. Therefore, population grid data was utilized as a reference indicator to optimize AED deployment.

Furthermore, no study has yet proposed an index that quantitatively measures the reasonableness of AED deployment. Determining whether the deployment of

AEDs in a particular area is reasonable based on a uniform standard is impossible because it is not conducive to the rapid improvement of social emergency response capacity. This study's strategy for improving AED deployment addresses a vacuum in the existing academic field and is predicted to be valuable for future research.

3. Model

Based on the AED location data and population grid data for Beijing, Shanghai, and Shenzhen, this study uses QGIS to determine the population grid covered by AEDs and the number of AEDs per 100,000 as the new AED index.

The available locations of the new AEDs are computed using five-minute isochronous circles and an OD matrix derived from metro routes and road grids.

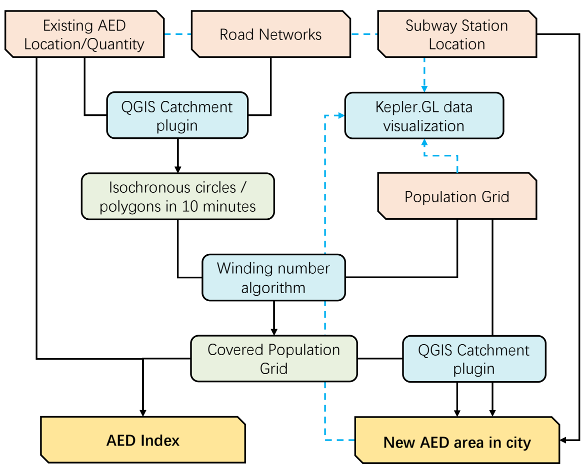

Figure 4. Flowchart

4.1. Isochronous circle analysis method

Given technical limitations, an isochrone (isochronous circle) is a region bounded by the same travel time, which previously could only be depicted using concentric circles. This method did not permit accurate quantitative calculations. With the development of GIS technology, drawing isochronous circles for various modes of transportation based on the existing road traffic network and road access levels is now possible. Currently, the isochronous circle is an irregular surface connecting the farthest distance points that can be reached in the same amount of time by road. In reachability analysis, it is more realistic than the isochronous circle constructed using concentric circles.

Figure 5. Urban road walking 5-, 10-, and 15-minute isochronous circles

4. Methodology and Data

During the data collection process, we discovered that no platform providing complete AED location information had been established in China. Therefore, the authors chose mobile application stores (such as APP Store) and search engines frequently employed by Chinese Internet users: search.weixin.qq.com (Weixin is a social networking software owned by Tencent Group with 1.2 billion users and the most widely used social networking software in China. The search function provided by Weixin is also widely used) and Baidu.com,. They searched for keywords such as "AED map," "AED location," and "AED distribution"; discovered H-Grace, Mindary Medical, and six other companies providing AED devices in China; and conducted an exhaustive search and data analysis. During the search procedure, we discovered that the number and position data of AEDs varied greatly from platform to platform because of diverse information sources.

This study used QGIS and Kepler.GL for data processing and visualization.

QGIS is an easy-to-use Open-Source GIS, the official proprietary software of the Open-Source Foundation for Geospatial (OSGeo), accessible on Linux, Unix, Mac OS X, and Android [27]. QGIS supports a variety of vector, raster, and database formats and functions, including callable algorithms. In contrast to the sophisticated but costly commercial program ArcGIS, one of the most user-friendly aspects of QGIS is that it is open source. QGIS also has its open-source plug-in community [26], where academics worldwide can apply and exchange plug-ins. The latest version of QGIS utilized in this study is 3.16.

Uber's Kepler.GL is an open-source data visualization tool for geographic data that accepts input via the Jupyter notebook API. Kepler.GL supports thematic maps, 3D, geographical calculations, and location visualization.

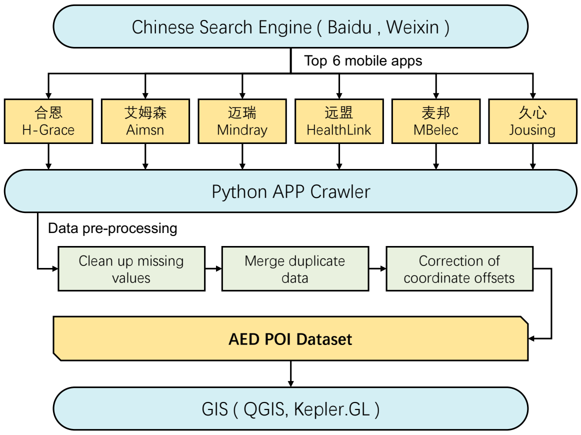

Figure 6. AED data acquisition and processing

The data from all top 6 apps were pooled to generate a more comprehensive AED dataset in this study.

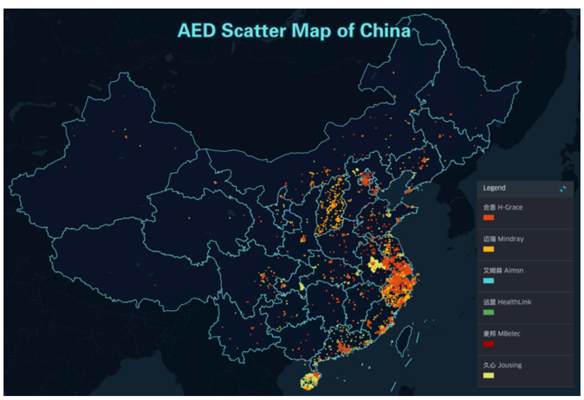

Figure 7. AED Scatter Map pf China

4.2. Population grid data

Regarding the selection of indicators for depicting the spatial distribution of the population, traditionally, census data were collected, stored, and analyzed with administrative areas as the basic statistical unit [23]. This statistical method has many practical application issues, including low spatial resolution and mismatch with other data spatial unit scales. With the development of GIS, RS, computers, and other technical means, the emergence of geographic grids that divide the earth's surface into different scales based on mathematical rules can more accurately reflect the spatial distribution of population, and population differences within administrative divisions can be depicted in greater detail at different division scales. The most prevalent population gridding approaches rely on remote sensing and land use data to parameterize population density models [16].

Population grid data combine population information with its geographic location and count the population distribution inside a predetermined spatial grid cell. The most important characteristic of population grid data is that it relies on many data sources (census data, resident population, and land use data) to improve the spatial accuracy of population data distribution.

This study's population grids were downloaded from Worldpop.org, which provides users with unrestricted access to worldwide geographic demographic data and may be used to research site demographics, dynamic population flows, and assess population status indicators. Users can directly download GIS data based on data categories and map previews.

The population grids are calibrated with UN population data. Below is a map of the population density of the kilometer grid cropped to the administrative boundaries of Beijing, Shanghai, and Shenzhen.

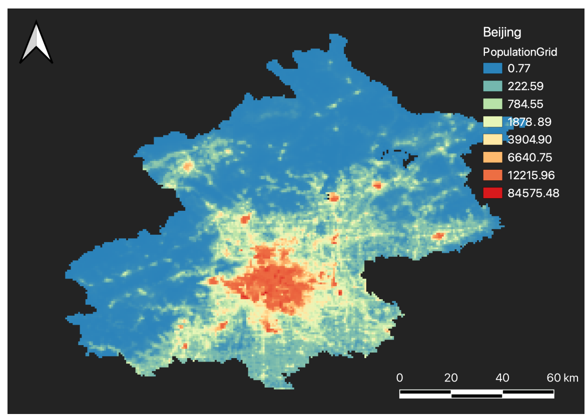

Figure 8. Population Density Map of Beijing

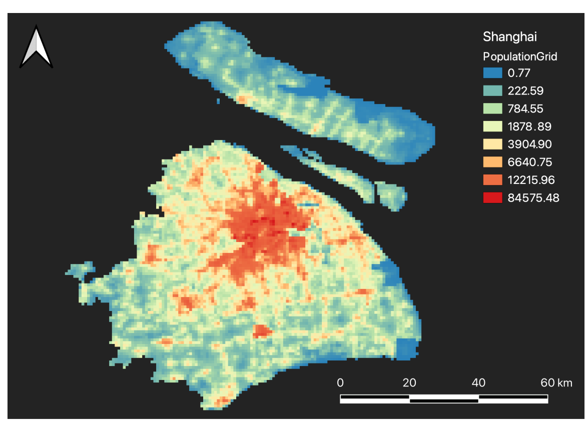

Figure 9. Population Density Map of Shanghai

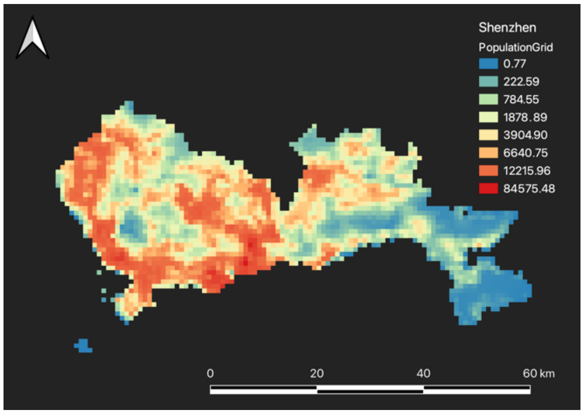

Figure 10. Population Density Map of Shenzhen

4.3. Road data

OpenStreetMap (OSM) is an open-source street map created in the United Kingdom in 2004 by Steve Coast. OSM is a world map that is entirely co-edited by the online public, with greater flexibility, universality, and data granularity than other mapping software. Furthermore, OSM is supported by open-source GIS software, such as QGIS, and data can be downloaded directly via QGIS at a faster update rate. Consequently, this study adopts the OSM road data as the source of data for road network analysis. The OSM road network is used to calculate travel times and generate isochrone polygons along the roads.

This study maps the transportation road networks of Beijing, Shanghai, and Shenzhen using their administrative borders as masks.

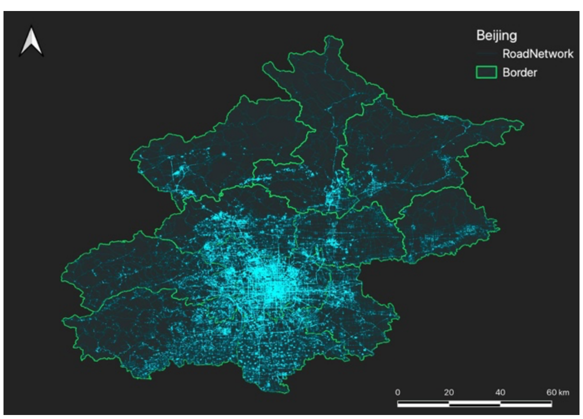

Figure 11. Beijing Traffic Road Network

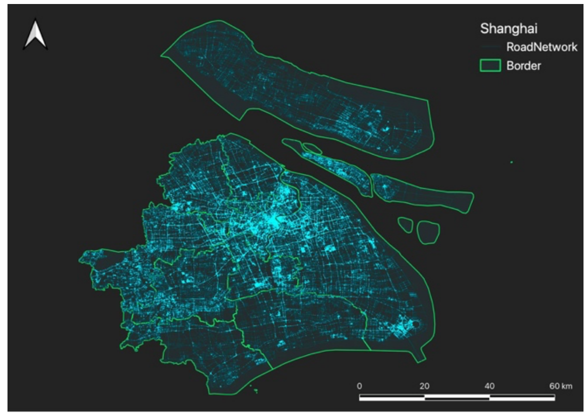

Figure 12. Shanghai Traffic Road Network

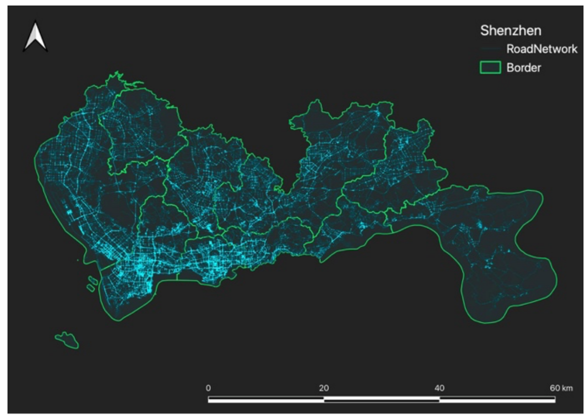

Figure 13. Shenzhen Traffic Road Network

4.4. Metro station data

The subway is a public environment with a high pedestrian density and a closed environment. OHCA is more likely to happen in the subway due to crowding-related physical and mental fatigue. On September 25, 2020, a 45-year-old passenger died unexpectedly of a heart attack in a Beijing subway station, sparking public concern about the placement of AEDs in public places. In April 2022, all Beijing subway stations were equipped with automated external defibrillators (AEDs), and all new opening line stations have also been outfitted with AEDs. AEDs have saved the lives of four passengers.

Table 1. Population and number of metro passengers

City	Population (ten thousand)	Average Daily Metro Passengers (ten thousand)	Passengers/ Population
Beijing	2,170.5	451.4	20.80%
Shanghai	2,489.43	547.1	21.98%
Shenzhen	1,756.01	370.6	21.10%

Statistics from the Annual Report on Transportation Development in Beijing in 2021 show that at least one-fifth of all urban residents move around daily using the subway.Subway stations are, therefore, the primary locations for AED deployment in this study. Metro station data for three cities, including line names, station names, and WGS84 latitude and longitude coordinates, were obtained using the Gaode Map open platform. If a metro station does not match an already existing AED, the location of that station will be recommended as the next location to deploy an AED.

5. Location Analytics

As of May 2022, Beijing, Shanghai, and Shenzhen have respective populations of 2170.5, 2489.43, and 17,560.1 ten thousand people, with a total of 987, 3687, and 9929 AEDs and 4.5, 14.8, and 56.5 AEDs per 100,000 people, resulting in an accessibility index of 17.90, 40.04, and 75.71. By removing the population that could not be covered by AEDs and calculating the number of AEDs per 100,000 people as the AED index, this new index calculation was more equitable and could promote AEDs to take care of a larger population in cities.

Table 2. AED Index

City	Population (ten thousand)	Population Covered by AEDs (10,000)	quantity of AEDs	AED Index
Beijing	2,170.5	551.32	987	17.90
Shanghai	2,489.43	920.78	3,687	40.04
Shenzhen	1,756.01	1,311.47	9,929	75.71

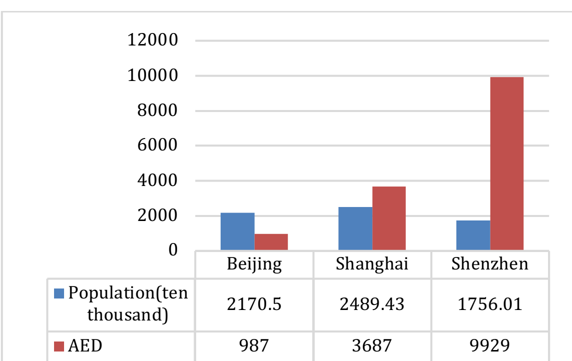

Figure 14. Comparison of population and the total number of AEDs in Beijing, Shanghai, and Shenzhen

The deployment of AEDs in Beijing is in its infancy. As a result of its late-stage advantage, the policy formulation is stronger, and the efforts were made in high-traffic areas, such as subway stations. Therefore, accessibility is good, and the starting situation is better.

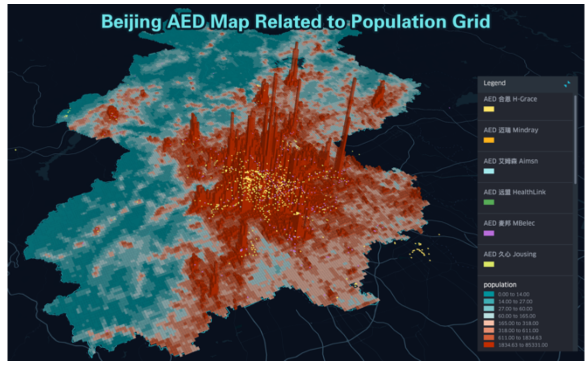

Figure 15. Beijing AED Map Related to Population Grid in 3D View

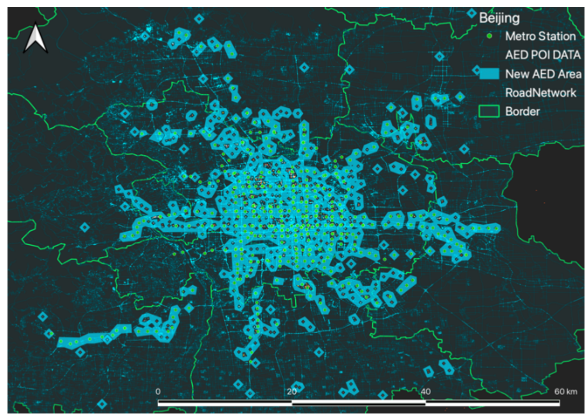

Figure 16. New AED area in Beijing

Beijing has a vast suburban area, with more mountainous areas in the north and a sparse population distribution, whereas the central city is densely populated but with long commuting routes. Beijing has a late start for AED installation and deployment with more than three suppliers for stadiums, subways, and public, commercial spaces. The installation of AEDs is mainly for public transportation routes. New AEDs are mainly recommended to be distributed to new subway lines, as well as in Haidian and Chaoyang's new industrial bases.

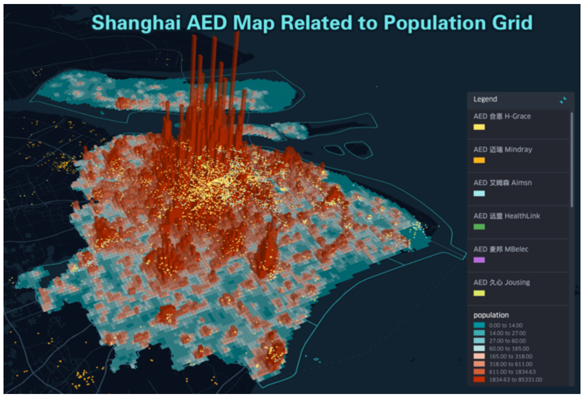

Figure 17. Shanghai AED Map Related to Population Grid in 3D View

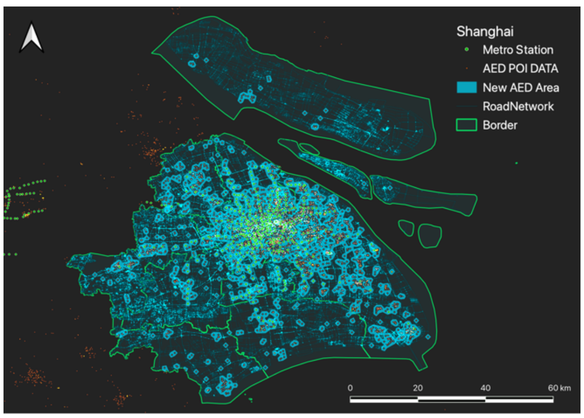

Figure 18. New AED area in Shanghai

As a coastal plain area, Shanghai has a population distribution pattern of high in the middle and low on all sides, with the central city and satellite cities connected by many subways and highways. Two major AED providers deploy AEDs in more overlapping locations, with fewer AEDs installed in surrounding traffic nodes and emerging industrial bases. Additional AEDs were mainly recommended to be distributed in satellite cities where the population is more concentrated.

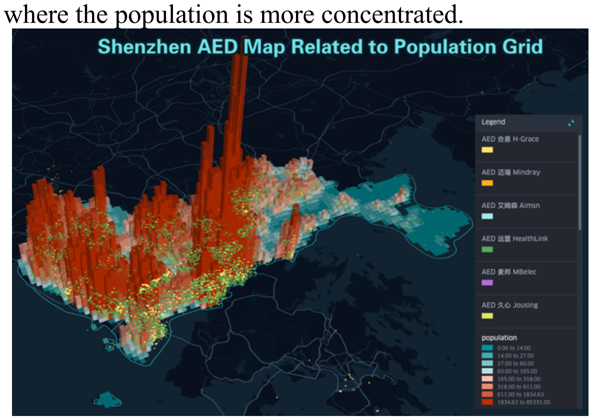

Figure 19. Shenzhen AED Map Related to Population Grid in 3D View

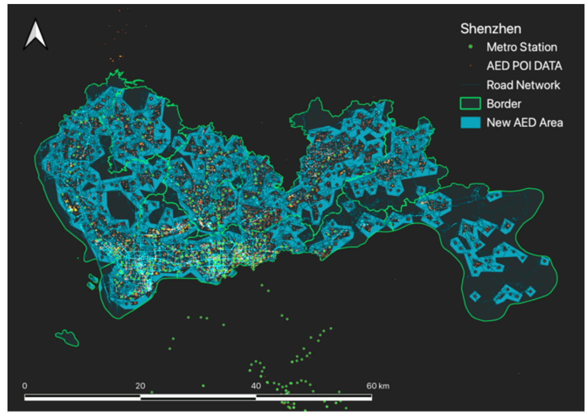

Figure 20. New AED area in Shenzhen

As a coastal city with a developed electronics industry, Shenzhen is more mature in AED installation and deployment and is far ahead of Beijing and Shanghai in terms of quantity. AED locations, population grid, and traffic lines overlapped with high planning rationality. Only one major supplier was assigned for construction and operation for better uniformity. Additional AEDs are mainly recommended to be distributed in new development areas in the east and on the metro extension routes.

6. Discussions and Suggestions

This theoretical and practical study examined a method for the prudent positioning of AEDs. We evaluated the equilibrium of AED deployment in major Chinese cities such as Beijing, Shanghai, and Shenzhen and found that areas with a high population density had an insufficient number of deployed AEDs and a deviation in population distribution from AEDs. The location of additional AEDs was then determined using GIS by evaluating the metropolitan area's population grid and public transit network. If more precise geographic data were available, such as population estimates derived from cell phone signals and accurate maps of building interiors, outcomes would be improved.

Given the limited number of AEDs in the city and varying platforms, prioritizing deployment to high-traffic areas can quickly improve coverage. This study established that Shanghai displays certain symptoms of investment duplication and imbalance, Shenzhen has a more developed model, and Beijing is rapidly approaching a breakthrough point in public transportation.

The AED maps and analysis in this work can aid cities in their future AED planning.

Below are our specific suggestions.

6.1. Unified Data Sources

During the process of data collecting, we discovered that, given diverse data sources, inconsistencies in the AED data were counted by each platform, resulting in more anxiety for patients searching for nearby AED devices and inefficient use of resources.

Thus, we propose that the information of AEDs and other first aid facilities be connected to the 120 emergency commands and dispatch systems in each city and nationwide and that the automatically docked information include the specific location, battery power, and whether it is in the normal available state to realize the effective connection between social and professional emergency.

Airports, railway stations, urban rail transit stations, transportation hubs, long-distance passenger stations, and other significant public locations, as well as tourist attractions, huge stadiums, large supermarkets, theaters, and schools, should improve their AED equipment configuration.

Furthermore, the AED and accompanying first aid facilities and equipment should have a consistent logo, placed on a device with external AED operation instructions or an operational flowchart with red and white as predominant colors.

6.2. Optimize Deployment Sites

The placement of AEDs in public places has been proven to be valuable in many studies [19]. Given the incidence of sudden cardiac arrest and the environment of the place, AEDs and other first aid facilities should be installed in locations with high traffic flow, high incidence of sudden cardiac arrest, and obvious locations. They should be easy to find; convenient to access; unblocked by other objects; and placed at various service desks, medical offices, first aid points and other locations manned by dedicated personnel. Public AEDs and other first aid facilities and equipment should be installed following unified guidelines, with signs so that rescue personnel can quickly access them. The electronic map of the city's AEDs and guidelines for their use can be released through the open government data platform to facilitate public inquiries and use.

6.3. Increase budgets and enhance public training

As known from the above, the AED deployment rate in China is far below the international level, while the AED penetration rate is also low, even in the three major cities with priority development. In this case, the role of government regulation should be strengthened to increase the special funding for AEDs, such as introducing the costs of AED acquisition, installation, subsequent maintenance and renewal into the government budget, and supporting the participation of charities, enterprises and other social capital in improving public emergency facilities, thereby improving the speed of AED deployment and the coverage density.

Additionally, relevant legal policies and regulatory guidelines should be correspondingly revised, and first aid knowledge should be incorporated into the teacher training system or the curriculum. Courses and training activities on AED first aid knowledge should be frequently held in schools and workplaces to expand the knowledge penetration rate of the public. Each enterprise should be required to unify the logo of the AED devices it produces, and the device should be furnished with simple instructions for AED operation or an operation flow chart on the outside. On this basis, AED distribution maps should be issued and placed in conspicuous public places, so that people in need can have access to information about the location of nearby AEDs in the first place and get quick assistance.

7. Conclusions

The use of GIS can bring intuitive maps and rational calculations when planning the deployment location of AEDs, considering the spatial distribution of the population and transportation networks, preventing duplicate investments in high-density areas, and rapidly increasing the number of AEDs in unbalanced areas, which is important for the effectiveness improvement of public health.

The main contributions of this study are as follows:

1. The public was provided with dependable and exhaustive access to AED information.

2. Based on the economic perspective, GIS technology and population grid data were used to construct an AED deviation index to measure the rationality of AED layout and propose an optimization method.

This study aims to improve the application level of AED configuration in China, save the cost wasted by ineffective configuration, and further accelerate the construction of social emergency medical service system in China.

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