OXFORD JOURNAL
OF STUDENT
SCHOLARSHIP

When Distance Becomes Risk

Jessica Yang
jessica.esmeeyang@gmail.com

ABSTRACT

Access to hospital care remains inconsistent across the United States and around the world, despite improvements in healthcare systems and infrastructure. Approximately 35% of U.S. adults (about 91 million people) reported they cannot access or afford quality healthcare in 2024 [1]. Within the United States, limited access to hospitals disproportionately affects underserved rural communities and low-income neighborhoods, primarily due to hospital closures, workforce shortages, and long travel distances. These barriers are critical in emergencies, where they can lead to life-or-death situations.
In this analysis, a variety of datasets have been employed to analyze the risk of hospital access on a national level.

Geographic accessibility is represented using U.S. county rurality classifications from the Department of Agriculture Rural-Urban Continuum Codes [11], which capture long-term geographic isolation and barriers to hospital access.

Healthcare system capacity is analyzed using county-level data on the number and location of acute care hospitals from the Centers for Medicare & Medicaid Services Provider of Services dataset [35] and the American Hospital Association Annual Survey [37].

Population vulnerability is represented using U.S. demographic data, with a focus on the proportion of residents aged 65 and older, derived from the Health Resources and Services Administration's Area Health Resources Files.

Risk analysis is conducted by constructing a composite index that identifies U.S. counties facing elevated structural risk of limited hospital access, rather than directly modeling disease-specific mortality or hospitalization outcomes.

This report provides a framework for analyzing healthcare access as a structural risk. Risk is the likelihood of limited access to healthcare, calculated based on structural geographic accessibility. The modeling approach emphasizes transparency and broad applicability by treating hospital access risk as a structural condition shaped by infrastructure and socioeconomic factors, rather than as a fluctuating variable. While this report focuses on quantifying structural access risks, existing research consistently links increased travel distance and delayed hospital access to higher mortality rates, worse outcomes for time-sensitive conditions, and increased healthcare costs due to delayed treatment, healthcare system

capacity, and population vulnerability indicators. This design allows the framework to be used across various regions without relying on overly complex or data-intensive methods.
The results from this model confirm that limited hospital access presents an ongoing and disproportionately distributed hazard across populations. Rural and poor populations experience higher levels of exposure to barriers to access, increasing the probability of delayed or forgone care and raising the risk of adverse health consequences. The severity of these outcomes is magnified by socioeconomic status—situations like poverty, uninsurance, and unstable housing conditions. Since the access limitation involved is structural, the health risks associated with it are likely to prevail over time without targeted intervention.

To reduce the likelihood of hospitalizations and mitigate financial risk for rural and low-income families, we have implemented multiple strategies. These measures aim to decrease the chances of developing certain health conditions, improve access to healthcare, and minimize the risk of financial crises in the event of a health issue. From a policy perspective, mitigating hospital access risks can reduce costly emergency interventions and preventable hospitalizations, allowing targeted investments in access infrastructure and mitigation strategies to yield long-term economic and public health benefits. We can establish health workshops and programs in rural areas to raise awareness about health and promote healthy lifestyles, which significantly lowers the risk of disease when followed. Additionally, to alleviate hospital overcrowding and ensure proper care, we can introduce a hospital-at-home program specifically for rural residents facing overwhelmed healthcare facilities. This program offers the same safety as traditional hospital care and often leads to improved mental health and increased physical activity. Finally, if a health condition does arise, having insurance and financial safety nets is crucial in avoiding a financial crisis. It is particularly important to focus on disseminating information about health insurance and how low-income families can apply for medical coverage.

This project offers a data-driven framework to understand and compare the risks associated with limited access to hospitals. The model and analysis aim to aid policymakers, healthcare administrators, providers, and public health officials in making informed decisions. This will help prioritize interventions and enhance healthcare access in underserved communities.

INTRODUCTION

Healthcare access is a vital aspect of public health, yet disparities in hospital availability persist worldwide. Specifically, geographic access to hospitals determines how quickly individuals receive care, which is particularly significant in emergencies. Despite advancements in medical technology and infrastructure, substantial parts of the population are separated from hospital services due to distance, cost, and systemic injustice. As hospital access declines, underserved populations face increased risk of delayed treatment, preventable hospitalizations, and adverse health outcomes, making hospital accessibility a critical public health and structural risk.

In 2021, over 4.5 billion individuals worldwide lacked full coverage of essential health services [1]. Within the United States, access to hospitals is unevenly distributed. Residents of low-income neighborhoods, even those in urban areas, often have limited access to healthcare because doctors leave poor neighborhoods to follow privately insured patients in affluent areas [2]. In addition, doctors are less likely to practice in low-income areas because reimbursement rates are lower, reimbursement delays are higher, and patient communication difficulties are greater (due to more non-English speakers or lower literacy rates) [2]. Thus, not only proximity, but socioeconomic conditions play a huge role in access to physicians.

Distance challenges are most prevalent in rural areas. In the rural southern United States, the average distance to the nearest hospital is 15.9 miles, or approximately 22.8 minutes [3]. When hospitals in these areas close, the burden increases exponentially. In fact, residents affected by rural hospital closures travel approximately 20 additional miles for general care [4]. Increased travel requirements force vulnerable populations at high risk of intensifying strain on healthcare facilities. Across the United States, distance to the nearest hospital varies widely, ranging from under 5 miles in dense urban centers to over 30 miles in many rural and underserved regions, where travel time rather than physical distance becomes the primary barrier to timely care [39]. In metropolitan areas, traffic congestion and transportation access can result in travel times exceeding 30 minutes despite relatively short geographic distances [40]. These increased travel requirements disproportionately affect vulnerable populations, including the elderly, individuals with chronic illnesses, and those with limited transportation options, thereby increasing strain on both patients and remaining healthcare facilities.

Extended travel distance and time have direct consequences for health outcomes. Longer journeys to hospitals can result in delayed treatment, reduced use of preventive services, and increased likelihood of avoiding care altogether [5]. County-level data further demonstrate that regions with limited hospital access experience higher rates of preventable hospitalizations for medical conditions that could be managed with timely care [6]. As hospital closures continue and disparities persist, limited access to hospitals represents a growing public health risk with both health and economic implications. This analysis is intended to inform government officials and policymakers, healthcare administrators, healthcare providers, and public health officials responsible for healthcare planning and resource allocation.

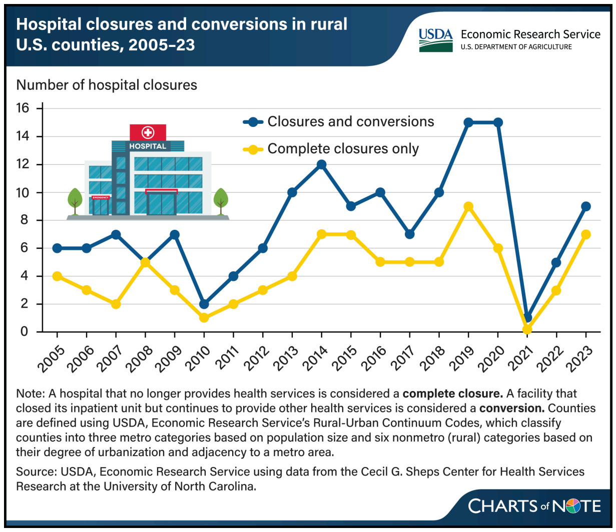

Figure 1: Annual hospital closures in rural U.S. counties (2010–2023).
The figure shows a pronounced spike in closures during 2020–2021 and a sustained increase through 2023, indicating that rural hospital closures are not solely a temporary pandemic effect but a persistent structural risk affecting long-term healthcare access (Economic Research Service [11]).

Although mitigation strategies such as telehealth expansion and emergency transportation programs have reduced some access barriers, they have not eliminated the underlying risks associated with hospital scarcity. Many communities remain dependent on distant facilities, leaving them exposed to delayed treatment and preventable adverse outcomes. These ongoing challenges demonstrate the need for a systematic, risk-based evaluation of hospital access to identify populations most at risk and to inform targeted interventions. By systematically evaluating hospital access through a risk-based framework, this project aims to identify high-risk regions and support data-driven strategies that reduce care delays and improve health outcomes.

2.1 Scope of Risk and Modeling Objective

Limited hospital access presents systemic risks that extend beyond increased travel distance alone. When individuals must travel farther to receive care, health outcomes are directly affected. Increases in travel distance lead to delays in receiving adequate care or completely forgoing care [6]. These delays are especially dangerous in emergencies, where time is a deciding factor between recovery and severe complications. For policymakers and healthcare administrators, this highlights how access barriers translate into tangible risks for patient safety and population health. These access limitations interact with transportation availability, emergency response capacity, and the distribution of the healthcare workforce, amplifying risk across the broader healthcare system.

Workforce shortages further limit effective access to care in rural and underserved communities. These areas “often have fewer health professionals,” with “about two-thirds of Dental Health Professional Shortages” located in rural regions [7]. Although this statistic focuses on dental care, it reflects a broader trend of provider scarcity that restricts preventive and emergency services alike. Limited staffing reduces system capacity and exacerbates the consequences of hospital closures, even when facilities remain physically accessible.

Hospital closures compound both distance and workforce challenges. Having a local hospital or access to care is critical in an emergency where minutes can make a big difference,” yet reports that “more than 100 (or 4% of) rural hospitals closed from 2013 through 2020” [8]. As a result, affected residents were required to “travel about 20 miles farther for common services like inpatient care, and 40 miles farther for less common services” such as substance misuse treatment [8]. These increases signal a systemic erosion of healthcare access that disproportionately affects rural populations.

For government officials, healthcare providers, and public health leaders, these findings highlight the importance of viewing hospital accessibility as a structure embedded within healthcare systems. Increased travel distances, provider shortages, and hospital closures collectively heighten the likelihood of delayed treatment, missed care, and preventable health outcomes. Addressing these risks requires coordinated policy and planning efforts informed by data-driven analysis of where access limitations pose the greatest threat. The modeling objective of this project is to quantify hospital access risk using measurable indicators such as travel distance and service availability to support equitable healthcare planning.

2.2 Assumptions & Constraints

This project has made several assumptions and considerations in relation to its scope and the analysis of results. First, we assumed in this analysis that the publicly available data sources that we used in this project provide an accurate reflection of the situation existing in the affected community with respect to the chosen variables. Second, there are restrictions on the availability of the data. There are variables like individual-level behavioral variables that have not been put into the model. This results in approximations. Lastly, financial viability is assessed at a general level as opposed to conducting a cost assessment. Even though it is intended to be practical and scalable, putting it into practice would require more testing and a more detailed review of available resources, which is beyond the scope of this phase of the project.

2.3 Next Steps and Phase 2 Analysis Plan

This particular project aims to build and validate a model to predict the risks involved in attaining hospital access as measured on a county basis and as applied to the United States, utilizing existing structural data, keeping the present phase of the study dedicated to model development and validation through distribution and structure study, as opposed to outcome prediction and long-term forecasting.

Further extensions of this research may include detailed travel time calculations, result validation based upon access-sensitive health indicators, and temporal analysis of hospital infrastructure. The extensions can help refine this model even more. The model can then be refined and may further help evaluate particular interventions or investments. However, this has been out of the scope for this particular project and is identified as a potential direction for continued research.

DATA METHODOLOGY

This section highlights the sources and processing of the data utilized in the hospital access risk model. The hospital access factor is a structural characteristic that is affected by geography, hospital infrastructure, and socioeconomic conditions. Thus, the data used in this analysis focus on long-term trends rather than variations.

As presented in the Actuarial Process Guide, sources were selected to address three broad categories:

1. Data describing or for refining categories of potential outcomes related to limitations on hospital access
2. Data for determining the severity of the range of loss in relation to the lack of access to hospital care
3. Data to establish the frequency or probability of those outcomes

All of the data gathered was assessed for reliability. We gave preference to data gathered by peer-reviewed research institutions and government agencies. When multiple sources were available, we compared definitions and data to check for consistency.

Data Identification and Collection

The analysis, modeling, data inputs, and conclusions are all restricted to the United States to ensure relevance, accuracy, and applicability to policy. The study further limits itself to data derived from nationally maintained datasets with consistent geographic resolution, which is available at the county or census tract level. In this context, the scope allows for direct interpretation relevant to U.S. policymakers, healthcare administrators, insurers, and public health officials.

All the variables were chosen to reflect the long-term structural characteristics of access to hospitals in the United States, rather than short-run variation or international comparisons.

Geographic Accessibility Data

Geographic accessibility was represented using county-level rurality classifications rather than modeled travel time estimates. Rural-Urban Continuum Codes data, published by the US Department of Agriculture Economic Research Service, were used to classify counties based on population size, level of urbanization, and adjacency to metropolitan counties [11].

The RUCC data capture existing geographic isolation and structural barriers to accessibility that affect hospital accessibility, especially in rural and remote areas. The proxy method ensures consistency nationwide and corresponds to the geographic accessibility element of the mathematical model.

Population Vulnerability and Contextual Data

The population vulnerability indicators were based on several variables provided by the U.S. Census Bureau [13], which made use of the American Community Survey and CDC Social Vulnerability Index [15]. Indicators were based on several variables, which included, but were not limited to, poverty rates, population ages, insurance coverage, and disabilities.

These measures aim to assess the capacity of populations to overcome access barriers using alternative transportation modes, financial means, or supplementary healthcare arrangements. A higher vulnerability score implies a higher likelihood of health problems developing due to access limitations to hospitals.

To guarantee reliability and comparability, especially within the context of the United States, it is essential that, within this project, primary data is chosen for use from nationally maintained datasets that have comparable definitions and geographic extent. Primary data was selected from prominent datasets maintained by the U.S. government. The steps taken to improve reliability are:

- Cross-checking the number and location of hospital facilities among various data sets, such as the CMS Provider of Services and the AHA [35][37].
- Standardizing geographic units to the county level to ensure consistency in the aggregation of all variables
- Validating the demographic and socio-economic data using Census Bureau products like the ACS, CDC/USDA classification systems
- Flagging counties with missing or suppressed values and removing them.

This process helps reduce bias stemming from uneven data reporting and makes the results easier to interpret with a focus on policy analysis within the U.S. itself.

Data Coverage and Limitations

Even though U.S.-based datasets have good coverage, there are some drawbacks. First, facility-level datasets can diverge depending on their categorization of hospitals, which can either be acute or specialty, as well as differences between operating locations and satellites. Hospitals could be missing depending on reporting locations, ownership, or mergers.

Second, the travel times characterize “normal” conditions, which cannot account for extreme weather conditions, congested road conditions, road closures, lack of vehicle access, and emergency medical response times.

Third, in focusing attention on counties, smaller inclusions of population can occur in well-served areas as well as in less well-served areas of large counties. Likewise, in regard to vulnerability, data in ACS or index measures, such as SVI, can have errors in smaller population groups.

Such limitations will not exclude or preempt the usefulness of the given model, but it must be used very cautiously to understand definite rankings. The model should be used to figure out locations that are at-risk to be targeted by intervention.

MATHEMATICS METHODOLOGY

All mathematical definitions, variables, and results in the following section pertain only to the United States. Each region i corresponds to a U.S. county, and all model inputs are based on domestic healthcare infrastructure, population, and accessibility data. The underlying math of the model remains identical to its generalized form, but all interpretations, normalization, and application of that math are constrained to the national setting.

The hospital access risk model is defined as a composite index developed for each U.S. county i. The risk score R_i is expressed as:

$$R_i = \alpha + \beta_1 T_i + \beta_2 H_i + \beta_3 P_i$$

where:

- R_i is the composite hospital access risk score for the county i
- T_i is the geographic accessibility risk component
- H_i is the healthcare system's capacity risk component
- P_i is the population vulnerability component
- β_1, β_2, β_3 are weighting parameters
- α is used to denote a basic structural level of access risk to hospitals, which is inherent across counties. Although some counties might have relatively better access to hospitals, it is important to note that there is always inherent risk when healthcare concerns are involved, which can relate to uncertainties such as workforce shortages, capacity, and emergency variables.

Parameters β_1, β_2, and β_3 control the weightings for the importance of each factor. In this phase of the analysis, equal weighting is used to maximize interpretability and avoid overfitting in the absence of outcome-based calibration. It should be noted that the purpose of this model is to identify risk at a structural level. Future extensions of this model could utilize regression analysis for such results against relevant access-related outcomes, such as preventable hospitalizations and mortality among the emergency population.

The total risk score Ri reflects the risk of hospital access, which is a risk and not a specific probability. The higher the risk score, the higher the risk of negative results related to the lack of hospital access. The composite-index structure follows standard guidance for constructing and interpreting composite indicators in a transparent way [30].

Description of Model Components

The model brings together three different dimensions of hospital access. Each dimension represents a different mechanism for the transformation of access limitation into health risk. The three different dimensions relate to structural issues with accessible healthcare, geographical issues with accessible healthcare, and issues with vulnerable populations.

Geographic Accessibility Component

Geographic accessibility risks rely on a "proxy measure" derived from rurality rather than estimates from travel times to hospitals. Rurality is measured by the USDA Rural-Urban Continuum Codes [11], which classifies U.S. counties on a scale from most urban to most rural. A greater value within RUCC corresponds to a larger geographic isolation and thus reduced physical access to any kind of hospital services.

T_i is defined as the RUCC value standardized to a 0-9 scale for each county i, so higher values correspond to greater expected geographic barriers to hospital access. This captures long-run structural accessibility constraints and corresponds to the county-level resolution of the data in this model.

Healthcare System Capacity Component

Health system capacity measures the availability of hospitals in relation to the population [35]. Even when hospitals are accessible, even at a local level, the capacity can be too small, leading to crowding and delayed care.

Capacity risk is modeled as an inverted hospital density measure:

$$H_i = 1 - \frac{Hospitals\ per\ 100{,}000\ population_i}{US\ Average(Hospitals\ per\ 100{,}000\ population)}$$

This way, a higher number is assigned to areas with fewer hospitals per capita. The inputs used to obtain facility and location information related to hospitals for this factor have been derived from information specific to the U.S., namely from the Centers for Medicare & Medicaid Services Provider of Services dataset [35] and from the Annual Survey conducted by the American Hospital Association [37]. This component reflects the structural limitations of health systems, which cannot be overcome by behavior [34].

Population Vulnerability Component

The population vulnerability captures the demographics that may have a tendency toward unfavorable consequences from restricted access in the event that they need hospital care in the future. In this case, it assumes that in the environment in the U.S., the vulnerable populations will be determined by those aged

65 or older in a county's residents' demographics in need of greater baseline levels of hospitalization, but with a reduced ability to compensate for access restrictions. For each county i, define the elderly share as:

$$E_i = \frac{Population\ age\ 65+\ in\ county\ i}{Total\ population\ in\ county\ i}$$

Model Assumptions

Many assumptions need to be made to apply the hospital access risk model:

1. County-Level Aggregation Assumption

   The model assumes that county averages provide a reasonable indication of access levels for those living within that county. Although variation may occur within counties, this assumption is necessary for developing a model at the national scale.
2. RUCC Proxy Assumption

   The model uses USDA Rural-Urban Continuum Codes as a county-level proxy for geographic isolation and travel burden, since it captures persistent structural rurality differences and is consistently available nationwide [11].
3. Additivity Assumption

   Geographic accessibility, healthcare system capacity, and population vulnerability are assumed to contribute additively to overall access risk rather than interactively. This improves interpretability and reduces the risk of overfitting.
4. Data Reliability Assumption

   The model presumes that domestic data sources for information regarding hospital locations, population counts, and vulnerability indicators were sufficiently accurate for use across U.S. counties, although some imprecision and/or absence was anticipated to arise.
5. Temporal Stability Assumption

   The relationships between access variables and risk are presumed to stay constant over a certain period of modeling, unless there are significant structural changes such as hospital closures, major policy interventions, and significant population changes.
6. Population Exposure Assumption

   The model bases its evaluation of hospital access risk as a structural characteristic at the county level, as opposed to evaluating the risk based on the general exposure of the total population. Therefore, the risk scores reflect the relative likelihood of access limitations occurring within a county, independent of total population size. Population size is incorporated during policy interpretation and prioritization, where higher-risk counties affecting larger populations may be assigned greater intervention priority. This separation allows the model to distinguish between structural risk and total exposure.

These are all made known specifically to maintain clarity and are based on the standards of actuarial models.

Examination of Model Accuracy

Given that it is a latent variable, model accuracy in explaining variation in hospital access risk can be evaluated using internal and structural validation rather than direct outcome prediction. The purpose of conducting this evaluation is to determine whether it differentiates well between counties and responds well to factors that determine access risk.

Figure 2 presents a graphical illustration of the actual distribution of composite hospital access risk scores in U.S counties. From this figure, a wide range of scores is presented, revealing meaningful differentiation across counties with varying structural access conditions. This is an important attribute of a successful model, revealing a degree of responsiveness in a composite index toward various aspects of input.

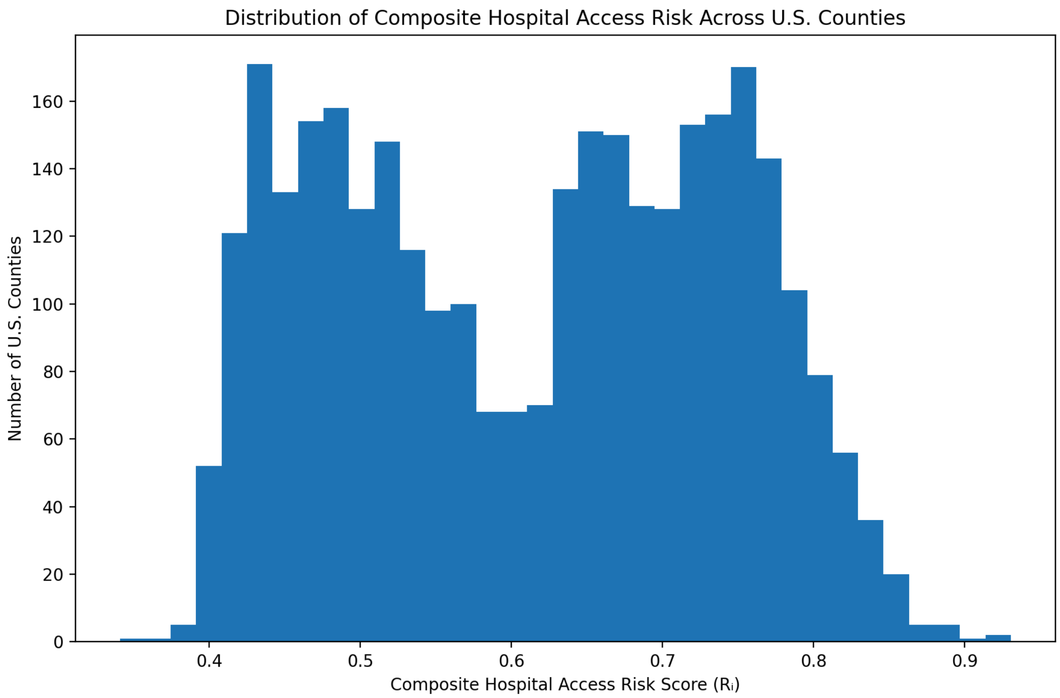

Figure 2: *The distribution of the composite hospital access risk score R_i across U.S. counties. The risk score integrates geographic accessibility, healthcare system capacity, and population vulnerability using county-level data from HRSA's Area Health Resources Files [12].*

Furthermore, in addition to distributional validation, the model is also tested for its responsiveness to geographic isolation. Figure 3 illustrates the responsiveness of composite hospital access risk as aggregate risk varies in counties sorted by the USDA's Rural Urban Continuum Codes classification system [11], in which higher codes represent more rural and remote geographic locations.

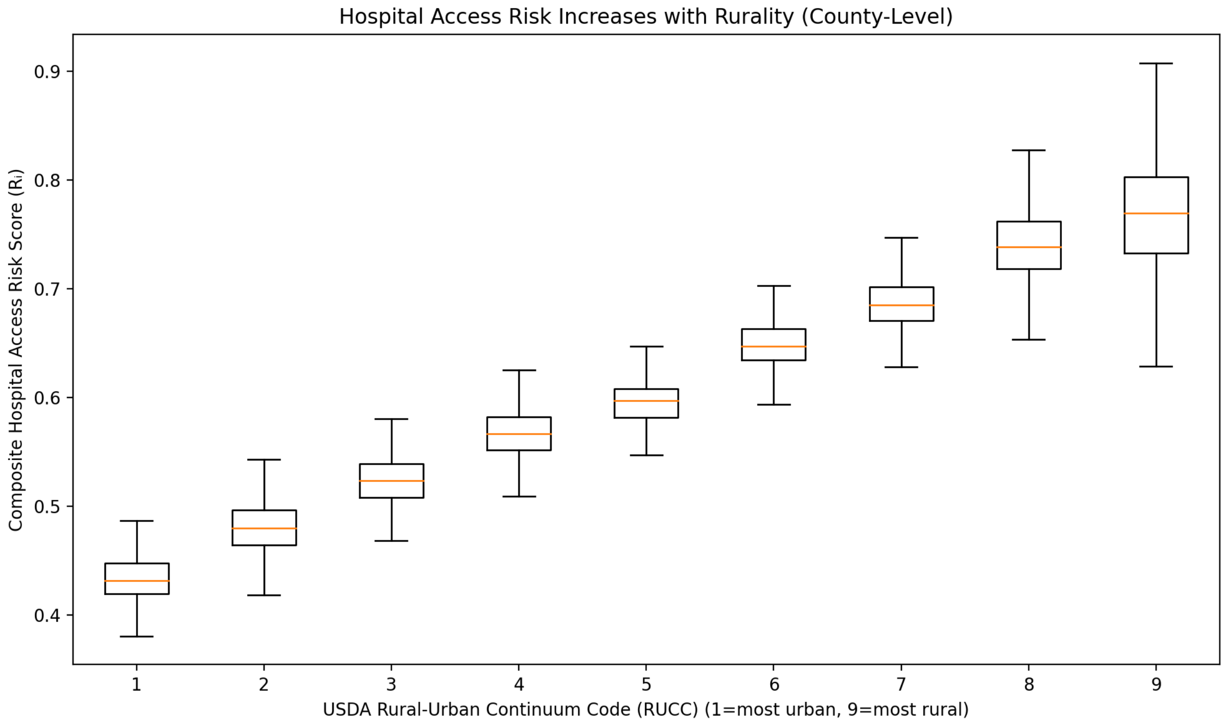

Figure 3: *Counties are grouped by the USDA Rural–Urban Continuum Code (RUCC), where higher values represent more rural and remote areas. The figure shows that counties classified as more rural consistently have higher composite hospital access risk scores, indicating greater structural barriers to hospital access in rural regions [11].*

Figure 3 illustrates that counties further into the domain of more rural populations tend to have progressively higher risk score values. Figure 3 shows how the composite hospital access risk score consistently responds to increasing levels of geographic isolation. Obviously, since geographic accessibility was included in this model, this represents internal consistency and interpretability rather than validation. Figure 3 verifies that this model behaves as it should in terms of known structural accessibility patterns. Figures 2 and 3 both verify interpretability and internal validity with regard to risk score values related to the hospital access risk model.

Conclusion of Mathematics Methodology

This Mathematics Methodology showed how the hospital access risk model is well-defined mathematically, consistent internally, and structurally sensitive to changes in geographic accessibility, healthcare system capacity, and population vulnerability within the United States. It was noted from the figures how well the risk model is interpretable and consistent as a model to identify areas where there is a high hospital access risk.

RISK ANALYSIS

Therefore, the risk score R_i indicates the structural likelihood of the occurrence of access-sensitive adverse outcomes in the county in question. In this context, the access-sensitive adverse outcomes include preventable hospitalizations, delayed treatment in the emergency room setting, and increased deaths due to conditions sensitive to inpatient treatment in a timely fashion. Existing literature suggests that when access to the hospital setting decreases in an area, so too does the positive outcome of the preventable hospitalizations in the region in question. As such, an increase R_i This model suggests an increased likelihood of adverse outcomes in the region in question.

Based on existing evidence, it can be concluded that the regions of the U.S. show a high probability of negative health outcomes, with rural locations at higher risk. In contrast, access to hospital-based health care is the main risk factor of concern identified by this analysis. Rural populations have higher death rates and risk of diabetes, stroke, and mental health crises. Access to healthcare plays a huge role, and people in low-income and poor households have worse access to care than high-income households for approximately 80% of access measures [19]. Socioeconomic status also plays a major role due to higher rates of uninsurance, medical debt, and inability to afford prescriptions. Additional circumstances like unstable food sources and housing can increase the risk of addictions and worsen existing or create new health problems [20].

Frequency, Severity, Likelihood, Uncertainty

Hospital access risk can be understood better by considering a combination of the frequency at which access incidents tend to happen, the severity associated with access consequence outcomes, the likelihood associated with the possible outcome occurrence when access fails, and the degree associated with the confidence level concerning the data available on hospital access. Expected loss is discussed qualitatively by examining how the reduced availability of hospitalization prompts a backlog of preventable hospitalizations and raises per-capita healthcare costs, according to existing literature on the U.S. healthcare system. Each will be examined below [8][11].

Frequency of Limited Hospital Access

The extent of limited access to healthcare varies by region, with rural counties having a larger problem than urban or suburban areas. The results of the model show that rural counties have a problem of poor access to hospitals due to their isolation and relative lack of access to hospitals compared to their population size. The existing evidence in the U.S indicates that rural areas experience poor access to hospital services due to a lack of healthcare infrastructure and their distance from urban areas.

Low-income regions also have more frequent access limitations regardless of their geographic designation. The worse the households' economic status, the worse access to care across most access measures, including facilities available, service affordability, and continuity of care for populations. The access limitations are found to be persistent, meaning hospital access risk in such regions is ongoing.

Severity of Adverse Health Outcomes

The scale of the consequences for the lack of hospital access is substantial. Existing evidence shows a higher rate of deaths from illnesses that are highly responsive to inpatient care within a short time span, such as trauma, stroke, deliveries, and chronic illnesses [9]. Rural residents always demonstrate higher rates of deaths from preventable causes than their urban counterparts. Lack of access to emergency care contributes to the possibility of acute illnesses becoming severe or even leading to death. Moreover, the loss of easy access to hospitals for care may precipitate chronic illnesses such as diabetes or cardiovascular events. Socioeconomic factors also contribute to aggravating the severity. People in lower socioeconomic conditions have a greater chance of being uninsured, underinsured, incurring debt related to healthcare, or deferring access to healthcare due to costs. Such conditions can worsen the severity of outcomes in situations where access to healthcare services is restricted, as relatively treatable conditions become emergencies.

Likelihood of Adverse Outcomes

A significant factor in determining the likelihood of negative health effects from limited access to care is the vulnerability of the population. The more vulnerable populations of lower-income families, elderly populations, or communities in rural areas will be unable to substitute their own resources, such as private ground transportation, personal finances, or other sources of care, to overcome the problem of lack of access to care.

The model data show that areas of high vulnerability have a greater probability of seeing access limits affect physical or mental health. For instance, unstable housing, food insecurity, and a lack of access to preventive services are associated with a higher probability of substance abuse disorders, serious mental problems, or unchecked chronic disease. In areas where the lack of hospital access is a problem, the calculated probability of serious outcomes becomes a highly probable event. Thus, even small barriers to access can have large consequences for highly at-risk groups.

Uncertainty and Data Limitations

While this model does provide a consistent framework for assessing the risk to hospital access, a number of sources of uncertainty persist. Estimates of geographic accessibility are based on modeled travel times, which cannot represent all aspects of local transportation availability or seasonal change. The databases of hospital facilities may incompletely capture informal or private hospitals, especially in underserved regions within the United States. Also, aggregation at the regional level may mask disparities within a region, for example, between urban centers and remote communities. Socioeconomic indicators also tend to be modelled or self-reported, which in itself introduces a degree of measurement uncertainty.

Even with these limitations, the consistency of findings from multiple independent data sets strengthens confidence in the overall patterns of risk identified. Uncertainty does not negate risk, but it does counsel caution in the interpretation of precise risk rankings.

Trends and Changes in the Risk Profile

The trends discussed in this section reflect documented patterns in hospital access and healthcare infrastructure rather than projections produced by the model itself. The risk of access to hospitals is not static. It reflects long-term needs in demography, healthcare infrastructure, and socioeconomic conditions. A set of trends will drive the future risk profile. Rapid population growth in poor regions is likely to heighten pressures on existing health systems in the absence of comparable growth in hospital supply. Urbanization may reduce some access barriers, but also exacerbate congestion in urban hospitals and displace rather than eliminate access risk. These gains in access face threats from hospital closures and health workforce shortages, most pronounced in rural areas. Simultaneously, economic insecurity and increasing health care costs may be heightening financial barriers to care and further elevating risk for vulnerable populations.

RECOMMENDATIONS

This report highlighted many causes of limited hospital access that pose a great risk to population health. The following recommendation strategies focus on behavior changes to lower the chance of bad health events, modifying outcomes to lessen the severity of consequences, and insurance to absorb financial loss.

The strategies proposed for mitigation, based on what has been discussed in this section, are all coherent with the specific factors included in the risk mode. Counties with elevated geographic inaccessibility risk (T_i) are prioritized for interventions that reduce reliance on physical proximity to hospitals, while counties with high healthcare system capacity risk (H_i) are targeted with strategies aimed at reducing inpatient demand. Counties with high population vulnerability risk (P_i) are best served by preventive and financial protection strategies that reduce baseline health and socioeconomic exposure. In fact, the proposed mitigation strategies are best implemented in counties with a high level of risk concerning geographic inaccessibility. Counties that have a high level of risk concerning the capacity of the healthcare system are best served with a strategy aimed at mitigating hospital congestion. Finally, counties that have a high level of population vulnerability risk are best served with the proposed preventive care program.

Behavior Changes

This recommendation is primarily informed by counties where the population vulnerability component (P_i) contributes most strongly to overall hospital access risk scores, indicating elevated baseline health risk independent of geographic proximity. Rural communities and low-income adults often have a higher prevalence of physical inactivity, obesity, heart disease, cancer, diabetes, and respiratory diseases [22]. These major noncommunicable diseases are responsible for over 70% of deaths, often driven by factors like smoking, poor diet, inactivity, and alcohol [23]. By implementing programs stressing activity, sobriety, and diet, the expected percentages of noncommunicable diseases could experience a significant decline. Health programs can be small workshops or informational sessions with health professionals. Often, small yet effective changes in lifestyle, like exercise and diet, usually lead to compounded health benefits. Pitching this to local county officials can be of great help, as they do not have to start a new health program themselves, but rather promote existing small businesses in food and exercise. For example, featuring a gym or yoga place in an article or local news, and providing large groups of people with discounts to incentivize them. Along with the recommended programs, they can include interviews from local physicians or health professionals to encourage health habits. This type of preventative care decreases the risk of illness, disease, and death, but rural patient adherence is lower than 55% [24]. This is a driving factor for physicians to leave rural areas, compounded by low wages [24]. When medical students rotated through a local clinic in Alabama in 2019, every adult patient had several gaps in preventive care, as they had not had access to healthcare in decades [24]. In a study in this rural clinic in Alabama, they used an EMR Integration, using an electronic medical record, and had medical students pre-enter screenings for diseases like hepatitis, shingles, colon cancer, and more. Thus, with this simple fix, the small clinic received much more compliance, allowing more patients to receive screening, even after the intervention.

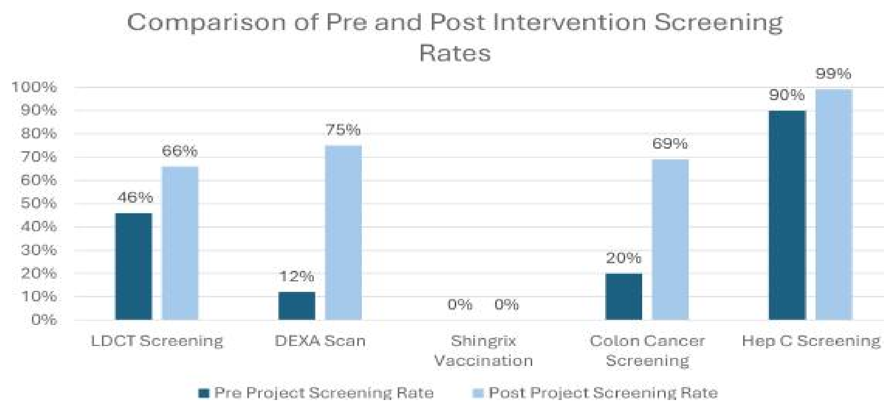

Figure 4: *This figure illustrates the rates of screenings and tests for common health conditions that affect everyone. The intervention involved medical students placing physical or digital reminders for physicians to order tests for patients, limiting it to one screening per appointment. The research determined that conducting only one test at a time was optimal, as it prevented overwhelming both the doctor and the patient. Consequently, the rates of screening showed a slight increase, even after the project ended, highlighting the effectiveness of this simple preventive care strategy for managing complex health conditions.*

Also, another way to prevent small sicknesses from turning into large conditions is through telehealth apps. Setting up online consultations or even asking simple questions to doctors instead of searching for symptoms on the internet can be a great relief. Health insurance companies and hospitals should specialize in online mobile apps or websites where patients can easily connect or set up quick, 15-minute meetings with a physician, nurse, or medical professional to ask simple questions before the illness gets too far. This can also speed up the pace of receiving health updates.

Modifying Outcomes

This strategy mitigates risk represented in the healthcare system capacity component H_i and reduces geographic access challenges reflected in T_i by decreasing reliance on physical hospital infrastructure. Another method to prevent hospitals from being overpopulated or overextended is through a hospital-at-home program. David Levine, MD, developed a hospital-at-home program in a rural area by examining adults who needed inpatient care for common, non-communicable diseases and patients from nearby hospitals. Nurses and paramedics would visit the patient in person twice per day, handling tasks like exams and medication. Doctors or nurse practitioners virtually visit the patient while wireless stickers are worn on their chest to keep track of vital signs, which are sent to the medical staff. The patients who received at-home care had significantly more satisfaction, a net score of 88.4, compared to a score of 45.5 from patients in the hospital [25]. Moreover, the at-home hospital costs less money, reducing costs by 27%. There was also an increase in mobility; patients often had 700 more steps per day than hospitalized patients, while also having no significant difference in patient safety or readmission rate. In addition to these benefits, the researchers also noted that for rural patients who live on farms, being on their own land and near their animals contributed to their mental well-being and recovery. This program can be pitched to local hospitals and department managers, along with the real effects and benefits of the real study from Dr. Levine.

Insurance

Insurance-based interventions are informed by counties with high population vulnerability risk (P_i), where financial barriers amplify the consequences of delayed or avoided care. Health insurance is a financial safety net if prevention and access strategies fail by absorbing economic shocks for low-income and rural households. Evidence shows that "health insurance schemes were associated with a 17% to 50% reduction in the odds of incurring catastrophic health expenditure, with the largest impact amongst poor households [26]. This significantly reduces the crises that poor households can fall into when medical bills arise. Similarly, health insurance reduced poverty attributable to out-of-pocket health spending by 7% to 12% [27]. Despite these benefits, many eligible adults remain uninsured, not because of ineligibility, but due to structural barriers such as complex enrollment and renewal processes. These challenges disproportionately affect low-income households, where language barriers and lower literacy rates increase the likelihood of losing coverage even when individuals qualify [28]. As a result, improving insurance access is less about creating new programs and more about reducing friction within existing systems. Often, the reason why adults do not have insurance is due to the complexity of renewal and enrollment processes, which causes people to still lose coverage when they qualify [28]. In this case, low-income households' language barrier and literacy rates play a major role. Simple methods that can be implemented are outreach and enrollment assistance in rural and low-income areas. Simply having translators, navigators, clinic assistants, and even social media and digital information can significantly increase enrollment in Medicaid by around 23 percent at a minimum [29]. In one experiment in California, a population of nearly 80,000 individuals who applied for Covered California Health insurance in 2019 but had not selected to enroll or delegate their case to an agent either received a phone call from a service representative or did not. The treatment group, just by receiving a phone call, had an enrollment increase of 53% [29]. This intervention reduces risk captured by the population vulnerability component (P_i) by lowering financial barriers that increase the likelihood and severity of delayed care.

Subgroups	Sample sizes[a]	Control-group enrollment rate (%)	Enrollment increase due to outbound call (percentage points)	Change in enrollment[b] (%)
Referred from Medicaid[c]				
Yes	49,020	5.4	2.9****[d]	53.7
No	29,981	22.8	2.1	9.2
Household income as percent of FPL				
<150%	10,437	8.4	4.0****[d]	47.6
150%–199%	24,194	11.0	4.0****[d]	36.4
200%–249%	15,266	11.4	1.3	11.4
250%–400%	13,974	15.2	1.7	11.2

Figure 5: *This table shows the 53% increase in enrollment as a result of a phone call from a representative of the health insurance. The treatment group received a call while the control group did not. The sample of the study was 79,522 individuals who had applied to obtain Covered California health insurance coverage for the 2019 coverage year but had neither selected and enrolled in a plan nor delegated their case to an insurance agent or navigator" [29].*

CONCLUSION

This study developed a county-level composite framework for evaluating hospital access risk across the United States by combining geographic accessibility in distance, healthcare system capacity, and population vulnerability into a single interpretable score. Additionally, this analysis reveals that hospital access is a structural public health issue shaped not only by rural distance but also availability of facility and demographic vulnerability of population.

The model separates different forces contributing to access risk, which makes it possible to identify why a county is vulnerable rather than only ranking where risk is highest. This impacts policy, because counties with similar scores can require different interventions depending on the main contributor to the score.

The model allows for a practical starting point for comparing counties and prioritizing intervention. Future work could strengthen the framework by adding travel-time estimates, emergency response factors, and validation against access-sensitive health outcomes such as hospitalizations and delayed treatment. This analysis supports how hospital access risk is a multidimensional structural problem than a single distance problem. Furthermore, there are mitigations to reduce risk. Thus, by analyzing the data and seeing which factor is most determinant in the risk score, local governments can select the appropriate mitigation strategy explained earlier.

Novel Findings

County (STATE)	Geographic Accessibility (T)	Health System Capacity (H)	Population Vulnerability (P)	Risk Score (R)	Main Factor
LA (CA)	1	0.51	0.16	1.67	H
Lincoln (NC)	1	0.39	0.2	1.59	H
Sedgwick (CO)	9	-8.28	0.32	1.04	H

Findings were created utilizing the mathematical data applied onto US counties. The three counties were randomly generated. From this data, we can see that health system capacity plays a significant role in the composite risk score. Looking at this data, a novel finding is discovered. The health system and system capacity is significant in determining risk of a county. However, there appears to be a strong correlation between geographic accessibility and health system capacity. Thus, there can be further research done on how geographic accessibility and capacity impact each other.

Health system capacity is the highest score in all three counties. Thus, the most direct recommendation could be modifying outcomes. This can be done through adding another hospital system that allows patients to be taken care of in their own home. This reduces the hospital's risk of being overfilled from patients who could benefit greater by being in their own home.

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