DASHBOARD DESIGN AND USABILITY STUDY FOR GEOSPATIALLY ENABLED INFORMATION SEEKING TO ASSIST PANDEMIC RESPONSE AND RESILIENCE

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Master of Science

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

DASHBOARD DESIGN AND USABILITY STUDY FOR GEOSPATIALLY ENABLED INFORMATION SEEKING TO ASSIST PANDEMIC RESPONSE AND RESILIENCE

Presented by Tiffany Young

A candidate for the degree of

Master of Science

And hereby certify that, in their opinion, it is worthy of acceptance.

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Dr. Ilker Ersoy

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Table of Contents

List of Figures

List of Tables

Abstract

Counties in Missouri are primarily rural. Rural communities often consist of individuals with poor health, lower economic status, and lack of public health infrastructure. During the COVID-19 pandemic, most research was centered around urban-based data and thus did not provide the full-picture of vulnerabilities present in rural counties for stakeholders to consider when proactively planning for pandemics and making policies in regards to mitigation.

To bridge the gap of urban and rural data availability, our team developed two interactive COVID-19 risk assessment dashboards using a 3-step design process that included identifying dashboard functionality based on the goals of stakeholders, collecting COVID-19 risk factor data, and selecting the appropriate type of dashboard visualizations in order for stakeholder needs to be met. Database processes were also created to promote a dynamic design in which risk factors can be easily updated, added, and removed from the risk assessment as COVID-19 progresses and more evidence is collected, keeping the risk assessment relevant. Using our dashboards, users can create customized risk assessments based on six categories of risk: susceptibility, transmission, accessibility, socioeconomic, health culture, and exposure, and geospatially visualize risk throughout counties with the ability to apply a rural/urban filter. Users can also drill-down to a specific county and learn about the prevalence and magnitude of 87 risk factors while looking for spatial trends and how counties with specific risk profiles were affected by COVID-19.

A usability study was conducted to ensure that our platform is meaningful and can be easily navigated to aid with pandemic mitigation, healthcare planning, and research. An

optimized version of this tool would not only help with planning for COVID-19 variants, future pandemics, and research in Missouri, but also be applied to all states of the United Stat

1. Introduction

1.1. Motivation

The coronavirus disease (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Quinn, Eldridge Houser, & Kapp, 2020), emerged in Wuhan, China in December 2019 marking the beginning of a world-wide pandemic (Wang, Horby, Hayden, & Gao, 2020). Cases of COVID-19 were first seen in the United States late January of 2020, and by mid-March, the transmission of the SARS-CoV-2 virus had accelerated, causing cases to quickly rise. Initially, COVID-19 spread throughout urban coast regions in the United States, later moving toward the rural communities in Spring 2020 (Mueller, et al., 2021). Approximately 63% of counties in the United States are considered rural. While these counties only contain 15% of the population, those living in these areas tend to be vulnerable due to poor health, socioeconomic status and lack of public health infrastructure (Paul, Arif, Adeyemi, Ghosh, & Han, 2020). Research regarding the impacts of the COVID-19 pandemic has focused on urban populations, limiting information about COVID-19 in the rural regions (Mueller, et al., 2021) and thus, making it more difficult for policymakers and practitioners to make informed decisions regarding preparation and mitigation in rural communities.

Missouri is composed of 115 counties, and 86% (99) of those counties are classified as rural (Quinn, Eldridge Houser, & Kapp, 2020). Each county has a unique risk factor profile that may need to be considered when enacting pandemic mitigation strategies and proactively planning for pandemics. To provide a platform where stakeholders such as planning committees at the

state, regional, and county levels as well as healthcare workers can learn about risk throughout Missouri rural counties, the "Geo-Context and Covid-19 in Missouri" website was created.

1.2. Literature Review

The aim of this study is to design an interactive risk-assessment tool that can assist with pandemic response, public health decisions, and health research. To examine existing systems, a literature review was conducted. The following review is reported according to the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (MJ, et al., 2021).

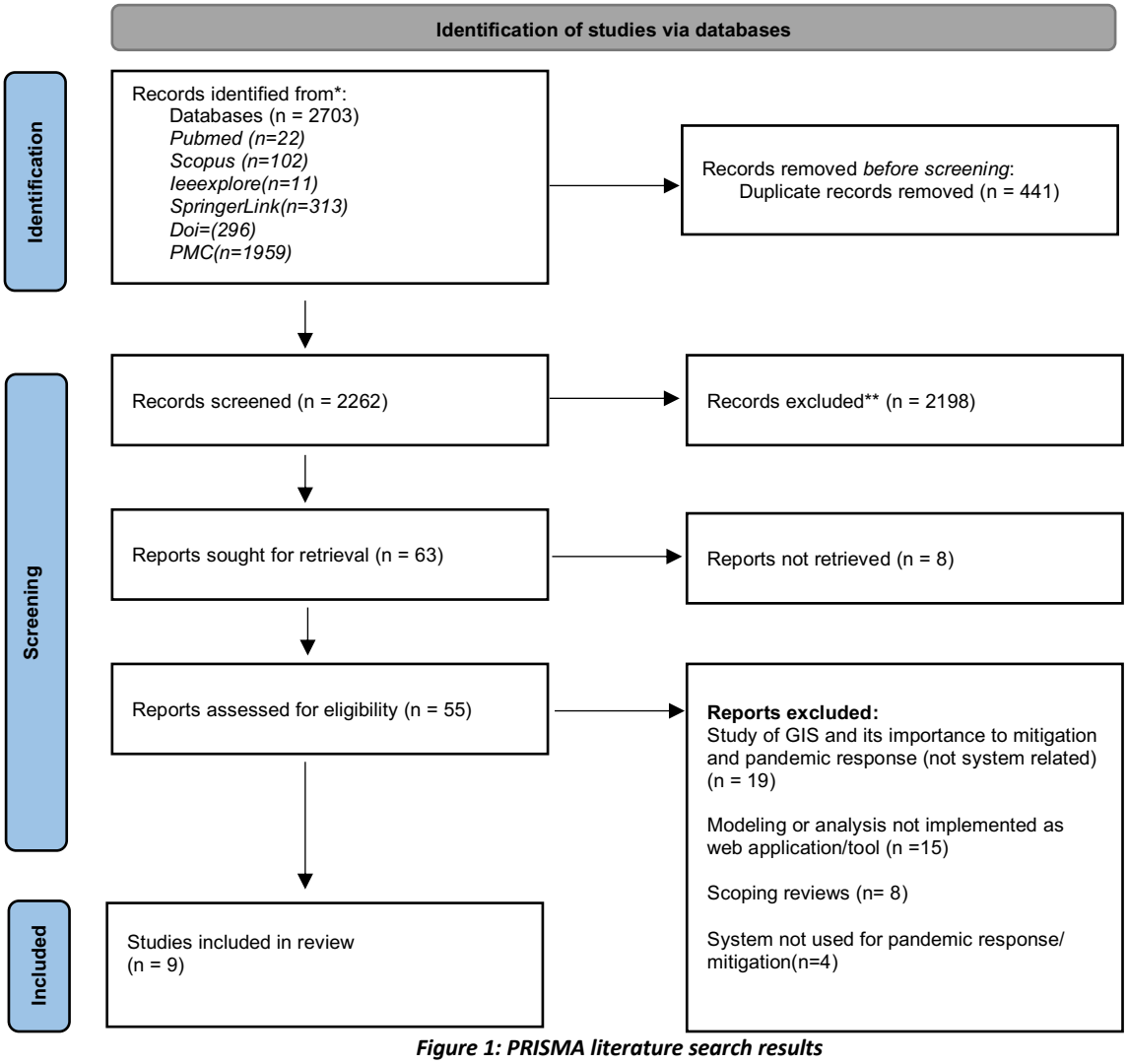


Figure 1: PRISMA literature search results

On September 4th, 2021, 2703 total records were identified for the query: ("pandemic" OR "outbreak" OR "COVID-19" OR "SARS-CoV-2") AND ("visualization" OR "dashboard" OR "web-based tool" OR "information seeking") AND ("GIS" OR "geospatial"). Databases queried were: PubMed (n=22), Scopus (n=102), IEEE Xplore (n=11), SpringerLink(n=33), ACM Digital Library (n=296) and PMC National Institutes of Health (n=1959). 441 duplicate records were identified and removed. 2262 record titles and abstracts were screened for content related to COVID-19/pandemic geospatial analysis and/or visualizations, geographic information systems /web-based applications, methods to support public health decisions (pandemic response and mitigation). 63 reports were sought for retrieval; 8 were not retrieved due to accessibility. Upon further screening, 9 articles fulfilled the inclusion criteria: development and design of a geographic information system or web-based application used to support public health decisions (pandemic response and mitigation) for COVID-19 or other pandemics. Four types of applications were observed in this review: surveillance/monitoring, outbreak detection, analysis of mitigation impact, and risk/vulnerability assessment.

The surveillance applications examined focus on the historical and current status of COVID-19 from a specific perspective of geography. *COVID-19 Dashboard* (Florez & Singh, 2020) presents a global view of COVID-19 case/death counts, case/death projections and mortality rates. *CovidCounties* (Arneson, et al., 2020) monitors COVID-19 in real-time at the county level and reports features such as estimated percentage of ICU beds, hospitalization rates, ICU rate and state mandates. The *GH COVID-19 dashboard* (A.K. & S., 2020) focuses on the regions of Ghana, Africa reporting COVID-19 trends, news, indicators, and changes in interregional mobility.

Outbreak detection is achieved in three vastly different ways. OUTBREAK (Arias-Carrasco, et al., 2021) is a tool used to generate interactive maps at various geographic levels from user-defined geographic and temporal data. It can be used to animate change over time and discover geo-spatial trends. DOT (Khedo, et al., 2020) is a crowdsourcing application that analyzes user-reported, disease-related symptoms and calculates the probability of the closest disease and the extent of outbreaks in specific locations. *SITAR* (Sistema de Informacio Territorial de Accion Rapida / Fast Action Territorial Information System) (Cos, Castillo, & Cantarero, 2020) projects how likely a COVID-19 outbreak is to occur in Catabria, Spain by considering the location of infected individuals, demographic and socioeconomic factors, and distribution of health areas (health centers, residencies, and pharmacies).

To measure mitigation impact, data from before and after mitigation techniques are enacted are studied. MapVaccines.com (Mast, et al., 2021) displays vaccination uptake at multiple geographic levels over time in the United States. The health impact of vaccination administration can used to identify hotspots (low vaccination rates and persistent disease rates) and aid with vaccination program planning. *GeoDS Lab - Mapping Mobility Changes in Response to COVID-19* dashboard (Gao, Rao, Kang, Liang, & Kruse, 2020) tracks time spent at home, mobility, and how mobility changed as a result of stay-at-home order mandates in United States.

Risk assessment applications provide insight into factors that may influence areas to be more susceptible to pandemic spread and increased severity. The COVID-19 Pandemic Vulnerability Index (PVI) Dashboard (Marvel, et al., 2021) considers factors of infection rate, population concentration, intervention measures, and healthcare vulnerability to create a

vulnerability score for counties throughout the United States. A summary of application content and visualizations are seen in **Table 1.**.

1.3. Our Approach

The "Geo-Context and Covid-19 in Missouri" website provides users with an interactive view of our team's COVID-19 risk assessment in Missouri. Counties are scored across six categories of risk: susceptibility, transmission, exposure, health culture, exposure, and socioeconomic risk. Features of surveillance (weekly state and county views of Covid-19 deaths and cases), outbreak detection (ability to visualize spatial trends and hotspot clusters) and mitigation impact (vaccination rates) are also introduced. Our website offers two features not seen in the literature:

1. Users can deep-dive into specific counties and explore the frequency and magnitude of **87** different risk factors.
2. Different combinations of risk categories can be selected to generate various risk assessments, rather than be limited to one, with a rural/urban filter that is applied to the geospatial visualization of the customized risk assessment.

The "Geo-Context and Covid-19 in Missouri" website will expand awareness about the attributes and risk of the rural counties in Missouri. Based on the characteristics of a county/region, healthcare and government planning committees can make more informed decisions about pandemic mitigation and address areas of deficiency. COVID-19 and healthcare researchers will have access to clean data from reliable data sources and a platform for preliminary data exploration. This platform can be used not only for COVID-19 but for future pandemics

Table 1: Application content and visualizations from literature

Covid Application	Geographic View	Features	Featured Visualizations
Covid-19 Dashboard	World View	• Cases • Deaths • Mortality Rate • Projected Cases • Projected Deaths	• Choropleth Map • Bar charts • Line chart (time series)
CovidCounties	County View (United States)	• Cases • Deaths • New Cases • New Deaths • %ICU Beds • Hospitalization Rate • ICU Rate • State Mandates	• Choropleth Map • Line charts (time series) • Cross Tab
GH Covid-19 Dashboard	Regional View (Ghana, Africa)	• Confirmed Cases • Deaths • Active • Recovered • News • 2020 Estimated Population • Population Density • Number of people 60+ • Number of one room houses • % One house room sharing one room • % multi-house sharing rooms • Mean number of	• Choropleth Map • Map with Markers • Bar Plot
OUTBREAK	Various geographic levels (user defined location)	• User defined variables • Time series	• Animated Map with markers (color customized) (Time series) • Histogram
DOT	District View (Mauritius, Africa)	• %Probability of Disease • Outbreak	• Map Chart
SITAR	Intra-urban (Cantabria, Spain)	• Total Population • Population between 15 and 34 years • Average annual income per household • Average household size • Cumulative Incidence • prevalence • Average age of the cases • Number of Cases • Distribution of Ages	• Map Chart with markers • Bar plot
MapVaccines.com	Various geographic levels (United States)	• Vaccination Uptake • %Vaccinated • Disease rate before and after vaccination • Vaccination rates • Hotspot identification	• Animated Choropleth Map • Heat Map • Line chart (time series)
GeoDS Lab - Mapping Mobility Changes in Response to COVID-19	County Level (United States)	• Percent Change in Mobility • Mobility (Median of Max Travel Distance) • Home Dwell Time	• Map • Line chart (time series) • Pie Chart • Bar Plots
The COVID-19 Pandemic Vulnerability Index (PVI) Dashboard	County Level (United States)	• Cases/Deaths • Death/Cases % • Population • Cases/Deaths per 100K • Vaccines • Transmissible Cases (population size/cases) • Disease Spread (Total cases in past 14 days) • Population Mobility (Daytime population density, Baseline traffic) • Residential Density (multi-unit structures, mobile homes, over forwarding, being without a vehicle, persons in institution group quarters) • Social distancing (mobility data) • Testing • Population demographics (%Black, %Native) • Air Pollution • Age distribution (%65+) • Comorbidities (Premature death, smoking, diabetes, Obesity) • Health disparities (Uninsured, socioeconomic status) • Hospital Beds • Hospital Ventilators	• Choropleth Map • Lie Chart (time series) • Bar plots • Crosstab • Histograms • Radar Charts

2. Geospatial Information

2.1. Risk Categories

SARS-CoV-2, is transmitted through respiratory droplets, contact routes, and through fomites in the immediate environment (WHO, 2021) Those who are 60 years or older and/or have underlying comorbidities such as cardiovascular disease, kidney disease, diabetes, smoking and cancer have an increased risk of contracting the virus (Cascella, Rajnik, Aleem, Dulebohn, & Napoli, 2021)**.** People from Black, Hispanic, and Asian ethnic groups also have a higher chance of contracting and dying from COVID-19 (Cascella, Rajnik, Aleem, Dulebohn, & Napoli, 2021)**.** There are many different avenues for risk when it comes to COVID-19 that our health assessment tries to capture. Our health assessment includes 87 risk factors across six categories of risk.

- The **Susceptibility** risk category contains factors that describe how predisposed individuals in a county may be to COVID-19. The percentage of the county population with comorbidities (diabetes, obesity, heart disease), the elderly population, smoking prevalence, and lack of health insurance are some factors measured.
- Factors in the **Transmission** risk category assess the spread of COVID-19 through human activity and population density. The percentage of commuters outside the county or state and the duration of travel are factors that can shed light on the movement of COVID-19 into and out of a specific county. Areas of high density such as colleges, nursing home establishments, and meat processing plants that have high transmission can be indicators of possible hotspots.

- Low vaccination acceptance and low willingness to be vaccinated can jeopardize herd immunity (Al-Amer, et al., 2021). The **Health Culture** risk category considers possible cultural and/or regional impacts to health maintenance through observed health care adherence, health screenings and previous vaccination participation.
- The **Socioeconomic** risk category contains demographic variables describing social context risk such as: race, ethnicity, disability, insurance status, and veterans' status. Factors such as median income and education status which are not commonly considered to be data of clinical interest when studying COVID-19 are also included in our risk assessment. Income can be an indicator of poor living conditions (overcrowded housing) and lower education level can be indirectly correlated to factors that increase the risk of developing COVID-19 such as poor nutrition and smoking habits (Khalatbari-Soltani, Cumming, Delpierre, & Kelly-Irving).
- Access to healthcare is necessary to treat symptoms and to prevent COVID-19 deaths. Where there is a lack of access, telemedicine has emerged as a way to maintain patient care and reduce the risk of exposure (A., S.D., & A., 2021). 56% of rural Missouri counties do not have hospitals and 71% of Missourians who live in rural counties do not have access to broadband internet, preventing the utilization of telehealth (Quinn, Eldridge Houser, & Kapp, 2020). Factors measuring access to hospitals, urgent care centers, clinics, telehealth options, broadband metrics and nursing homes are included in the **Accessibility** risk category.
- Existing exposure metrics such as cases, testing, deaths and positivity rate make up the **Exposure** risk category. Tests, cases, and deaths are normalized by county population to

allow for more meaningful comparisons. These risk factors are updated periodically and used to aid in the development of associations, correlations, trends, and surveillance. Implementing updated exposure metrics allows for our risk assessment to reflect the current state of COVID-19 in a county.

Table 2: Risk factors grouped into risk categories

Susceptibility (17 count)	Transmission (20 count)	Socioeconomic (18)
• %Leisure-Time Physical – Inactivity • Stroke Hospitalizations • No Health Insurance • %Obesity • %Diagnosed Diabetes • Nonadherence to Blood Pressure Medication • Annual PM 2.5ppm • Cardiovascular disease hospitalizations • Hypertension hospitalizations • Heart disease hospitalizations • Smoking prevalence • Smoking rate of change • %Uninsured • %Uninsured 65+ • %Uninsured 75+ • Age 65+ normalized • Age 75+ normalized	• Means of Transportation to Work (Carpool) • Means of Public Transportation to Work (exclude taxicab) • Place of Work – worked in state of residence outside of county • Place of Work – Worked outside of State • Travel time to work greater than 60min • Travel time to work less than 30min • Travel time to work less than 60min • Population density per square mile • Total nursing home beds • Nursing home establishments • Total meat processing workers • Total accommodations and food service workers • Total higher education – total enrollment • Total higher education – dormitory room capacity • %Occupants per room 1 to 1.5 • %Occupants per room greater than 1.5 • Housing unit density • %Households nonfamily with one or more 65+ • %Households nonfamily with one or more 65+ living alone • %Grandparents living with own grandchildren under 18 years	• Gini Index • %Hispanic or Latino any race • %African American • % with Disability • %Insured Hispanic • %Insured African American • %Insured with Disability • Rural Urban Continuum Code 2013 • %Veterans 18+ • %Veteran's age 65-74 • Estimate Median Income • Estimate Veteran Median Income • %Education – less than high school • %Education – Highschool graduate • %Education – Some college or associates degree • %Education – Bachelors or higher • %Status population 18-64 unemployment rate • %Total Population below poverty level
Health Culture (14)	**Exposure (8)**	**Accessibility (10)**
• Primary Care Physicians per capita • Dentists per capita • Mental Health Professionals per capita • Preventable hospitalization rate • %Annual mammogram • %Flu Vaccinations • %Colon Screened • %Mammogram in the past 2 years • %Pap Smear in the past 3 years • %Population with 1 dose of Covid-19 vaccination • %Population with full Covid-19 vaccination • Census 2000 participation rate • Census 2010 participation rate • All cancers all ages all sexes age adjusted incidence rate	• Positivity rate 1-7 days MO method • Positivity rate 2-7 days CDC method • Normalized total cases • Normalized total deaths • Normalized total tests • Normalized case 7 days • Normalized death 7 days • Normalized test 7 days	• %Population without broadband access • Most common download speed (proportion) • Most common upload speed (proportion) • BPR (2016) rural broadband % with access • Limited food accessibility • Average minimum travel time from county to hospital (min) • Average minimum travel time from county to Urgent Care (min) • Average minimum travel time from county to Public Health Clinic (min) • Average travel time from county to Nursing Home (min) • Average minimum travel time from county to telehealth (ECHO)

2.2. Risk Scores

To measure the level of risk in each county, the 87 risk factors are ranked on a quantile scale in the range from 1 to 5; 1 would be considered the "lowest risk" compared to the population (all Missouri counties) and 5 would be considered the "highest risk". To determine the range, the risk factor values of all Missouri counties are partitioned into five equal bins (quantile ranges). The bin in which a county's risk factor falls determines their "risk value" for that risk factor. For example, in **Figure 2**, 7.8% of Boone county's population has been diagnosed with diabetes; this value is found in the lower 20% of all population values (first quantile bin), thus having a risk value of 1.

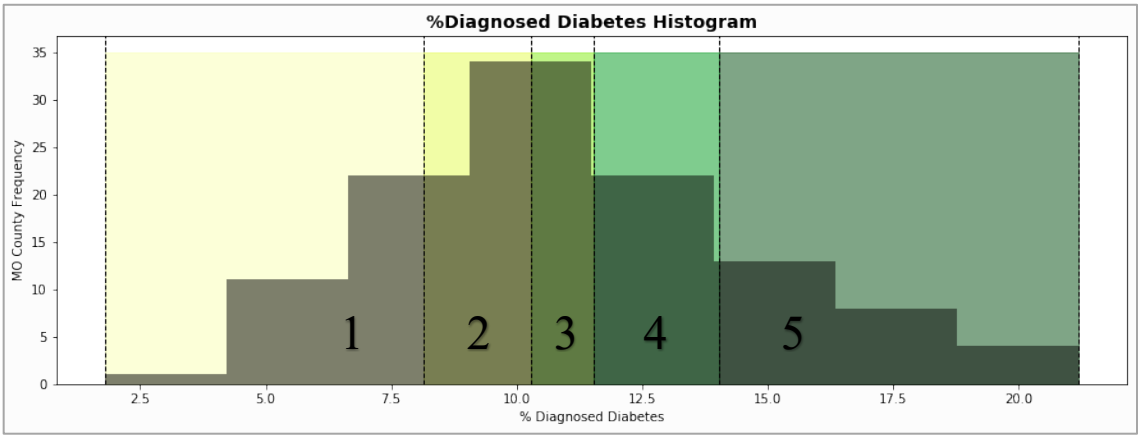


Figure 2:%Diagnosed Diabetes histogram partitioned into 5 equal bins with corresponding risk values

The risk values are the building blocks of all risk assessment scores and are used to create three scores: risk category score, total risk score, and customized risk score.

The **risk category score** is the sum of all risk factor risk values found in a risk category:

$$S_{risk} = \sum_{i=1}^{n} v_i$$

Equation 1: Risk Category Risk Score

where *n* is the total number of risk factors found in a risk category. For example, the sum of risk values of Boone County's health culture risk factors is 17 (**Table 3**); thus, the health culture risk category score is 17.

Table 3: Boone County's Health Culture Risk Category Score breakdown

Risk Factor	Risk Value
Census 2000 participation rate	2
Census 2010 participation rate	2
All Cancers, all ages, all sexes, Age Adjusted Incidence rate	2
Primary Care Physicians per captia	1
Dentists per captia	1
Mental Health Professionals per capita	1
Preventable Hospitalization rate	1
Percent Annual Mammogram	1
Percent Flu Vaccinations	1
Percent Colon Screened	1
Percent Mammogram in the past 2 years	1
Percent Pap Smear in the past 3 years	1
Percent population with 1 dose of COVID-19 vaccination	1
Percent population with full COVID-19 vaccination	1
Health Culture Risk Category Score	**17**

The **total risk score** is the sum of all six risk category scores:

$$Total_{risk} = \sum_{j=1}^{rc} S_{risk_j}$$

Equation 2: Total Risk Score

where *rc* refers to the total number of risk categories and S_{risk_j} is the risk category score of the j^{th} risk category. Boone county's total's risk score is 205. The calculation is as follows:

$$Boone\ County's\ Total_{risk} = S_{risk_{Health\ Culture}} + S_{risk_{Accessibility}} + S_{risk_{Transmission}} +$$

$$S_{risk_{Socioeconomic}} + S_{risk_{Exposure}} + S_{risk_{Susceptibilty}} = 17 + 28 + 68 + 45 + 24 + 23 = \mathbf{205.}$$

Lastly, **a customized total risk score** is a modified version of the total risk score where not all risk category risk scores are included in the calculation:

$$Customized\ Total_{risk} = \sum_{j=1}^{c} S_{risk_j}$$

Equation 3: Customized Risk Score

where c is the total number of selected risk factors. Boone County's customized risk total score for risk categories health culture and accessibility is:

$$Boone\ County's\ Customized\ Total_{risk} = S_{risk_{Health\ Culture}} + S_{risk_{Accessibility}}$$ = 17 + 28 = **45.**

3. Dashboard Design

Our dashboard designs were developed in three stages: identifying dashboard goals based on the needs of stakeholders, collecting data, and selecting the appropriate type of dashboard and visualizations.

The objective of our project is to bridge the gap between rural and urban data availability by creating a platform that stakeholders can refer to when planning, making public health decisions, and initial data exploration for research initiatives. Three types of stakeholders were identified at this time: members of organizations that drive policymaking at the state and/or local levels, health care employees involved in planning, and healthcare researchers. To inform different stakeholders about the vulnerabilities in a county, our team decided to create an interactive COVID-19 risk assessment through which users would be able to learn about risk in different regions of Missouri and then explore the different types of risk factors that make counties vulnerable. More specifically, using our platform would aid:

- policy makers in determining what types of mitigation measures may be necessary based on possible hotspot locations and/or transmission risk
- healthcare employees in planning for the possibility of increased need for hospital beds and other resources based on how susceptible individuals are in their communities or lack of healthcare infrastructure in surrounding counites
- researchers in conducting exploratory analysis by gaining access to clean data and reliable data sources

The second step of the design process was to collect COVID-19 risk factor data for all Missouri counties. This process involved referring to COVID-19 literature to determine relevant and important risk factors, getting access to data, validating that data was from a reliable source, and processing the data, making sure all values were present and in an appropriate data format.

Although data collection occurred throughout the design process, the third phase began when the first set of risk factors was gathered. This phase involved selecting the appropriate type of dashboard as well as visualizations. Dimensions from the *dashboard selection model* proposed by a computer science team at University of Gothenburg, Gothenburg, Sweden (M., K, & W, 2015) were referenced to guide discussion when designing the dashboard. Discussions involved what type of visuals would be needed for stakeholder needs to be met, how data would be inputted into the dashboard, how data would be delivered to the stakeholder, how often data would be updated, and the amount of data processing to be completed in the dashboard (additional calculations).

To keep our dashboards relevant and up-to-date, it was determined that data would be inputted into the dashboard from a database that could be updated periodically based on new COVID-19 developments or the availability of updated data. We aimed for this process to be as automated as possible and designed in such a way that risk factors could be added, removed, and/or updated, and the interface code would not require modification to reflect any changes. Database design and automation steps are discussed in in section **3.2 .** Due to the fact that many risk factor data sources update their datasets annually, and sometimes in longer intervals, a process in which data is pulled from various data sources was not created for the main risk factors. The sole factors which would require daily updates would be COVID-19 cases and death counts, and occasionally the exposure metrics. Before being stored in the database, all risk factor data was transformed into the appropriate data type format for storing. Once placed into the database, any additional processing would be done on the back end such as the derivation of risk scores used in the risk assessment, so that the only action that would need to take place when users are using the dashboards is an API call to retrieve data from the database which would result in decreased load times and improved user experience.

There are two levels to the COVID-19 risk assessment: risk categories and risk factors; where risk factors are used to create a risk category score and the risk category score is used to create the total risk score. These two levels build upon each other, and as a result a decision was reached that two dashboards would be created: *Risk Categories* and *Counties* where users can first learn about the different types of risk found throughout Missouri and then dive deeper to learn about the risk factors in a county. Thus, the type of dashboards that were created would be exploratory and informative which drove the thinking process behind the

visualizations. Developmental tools, database structure and management, and design elements of both dashboards are explained in the sections below.

3.1. Development tools

The *Geo-Context and COVID-19* website was built using Angular (version 9). Angular is a development platform built on typescript which is component-based and has a collection of libraries which allow the development, building, and testing of code (Angular, 2021). Python 3 was used to create the application programming interface (API) which makes calls to the *CovidDash* database and collects data that is used to produce dynamic visualizations, generated using the Plotly and Leaflet JavaScript graphing libraries. The website is hosted on a University of Missouri server at the domain name https://geoark.missouri.edu/.

3.2. Database Structure and Management

The *CovidDash* database was created using MongoDB and contains the following collections seen in **Figure 3**.

Each **risk category collection** is composed of json objects for a Missouri county with fields for the county FIPS, county name, attribute (risk factor) values, attribute risk value, and the risk category score (total). The **covid_sources** collection contains metadata for each risk factor including source information and a full description. The **category_totals** collection is a "summary" of risk category scores, total risk score, rural urban continuum attribute values, COVID-19 case totals and COVID-19 death totals for each county.

To ensure that our dashboards remain relevant and are able to scale in the future, the database was designed to have independent, base, **risk category collections** that are used to

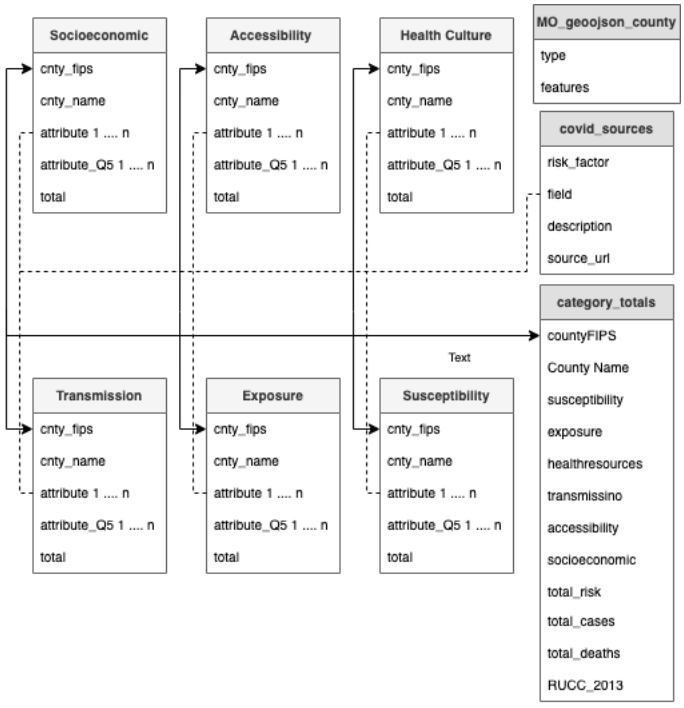


Figure 3: CovidDash database diagram

create the **category_totals** summary collection. **Category_totals** is updated daily at 3AM to retrieve updated COVID-19 cases and death counts. When there are changes to base collections, this collection is also updated to recalculate scores. Because the risk category collections are independent, risk factors can be added, removed, or updated without affecting other collections. When changes are made, the risk category score field “total” is re-calculated for each county.

A challenge that was encountered when first designing the risk category collections was the tailoring of front-end functions to work with dynamic datasets where risk factors can be added/removed without having to hard-code field names. To make this possible, each attribute risk value field name must be consistent with the following naming convention: [attribute field name]_Q5. The suffix “_Q5” is a flag used in the back-end function to update the risk category

score (“total”) in each risk category collection and is also used in the front-end functions. The following logic is used in functions to extract risk factor field names:

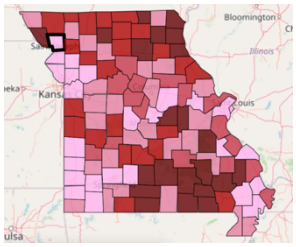
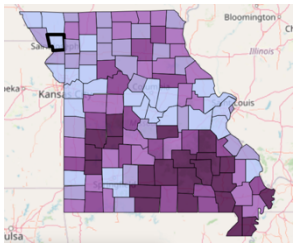
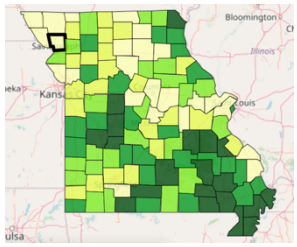
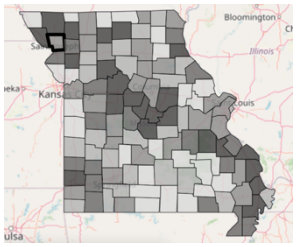
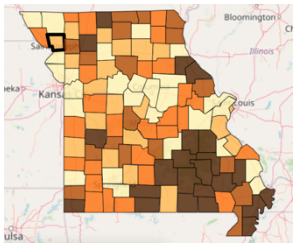
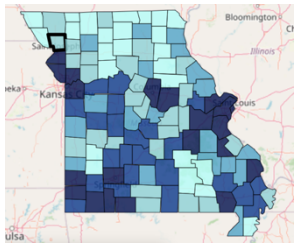
1. Query all data from risk category collection
2. Locate field names with suffix “_Q5” and store names in a list called “Q5”
3. Strip “_Q5” from Q5 elements and create a new list for risk factor field names
4. Loop through list with field names and create visualizations or carry out calculations

The JavaScript graphing library Leaflet was used to create map visualizations. Leaflet uses geoJSON, a data object used for encoding a variety of geographic data structures (geojson, 2016), to create geographic vectors in map visualizations. During development, functions retrieved the Missouri counties’ geoJSON object from a repository to create visualizations. Because our team did not own the repository, it was deemed unreliable and other options were explored. The size of the object was too large to compile when building the interface, thus the geoJSON object was deconstructed and stored in the *CovidDash* database in the **MO_geojson_county** collection. When map visuals are initially created on the dashboard, the data from this collection is pulled down and reconstructed into the format of a geoJSON object using the Pandas Python Package.

3.3. Counties Dashboard

The *Counties* dashboard allows users to drill down to a specific county and explore the different factors of each risk category and how they contribute to the risk assessment.

Table 4: Risk category color schemes

Accessibility	Socioeconomic	Susceptibility
		
Exposure	**Health Culture**	**Transmission**
		

Each risk category is assigned a color scheme seen in **Table 4** that is used in risk factor visualizations and the risk assessment pie radar chart. Color schemes promote a level of similarity among the features on the dashboard which can improve visual working memory, allowing users to store and process relevant information (Peterson & Berryhill, 2013) and help users associate risk factors to specific risk categories. Each color scheme is composed of five highly contrasted color shades so that spatial trends and/or clustering are pronounced and easily identified.

Bar plots were chosen to represent the risk factors because they can be used to depict distributions from large datasets and also compare summary statistics from multiple groups (Angra & Gardner, 2016) . As seen in **Figure 4**, each risk factor is presented with a bar. Individual bars are used to show risk factor values and how they compare with the Missouri county average, and max values. When looking at the bars as a complete unit, users can quickly

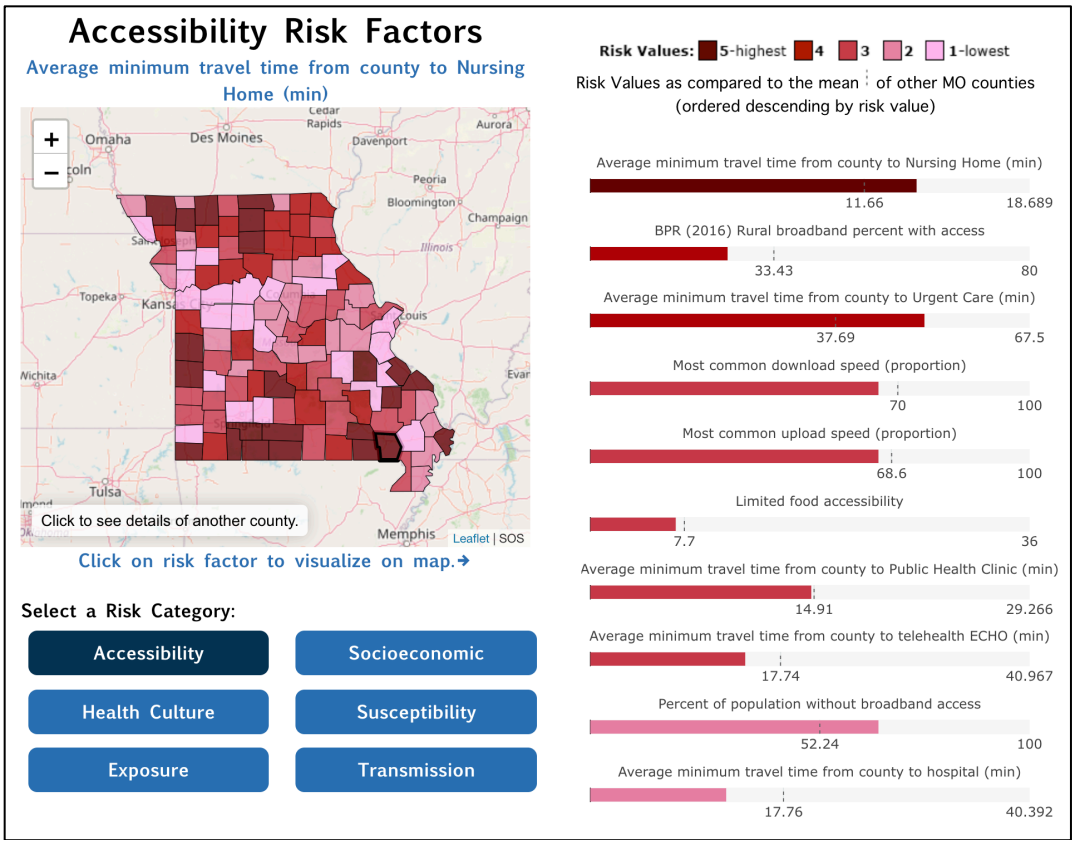


Figure 4: Risk factor visualizations - bar plot and choropleth map

identify which risk factors are most dominant in a county from the decreasing risk value order and color scheme. Darker shades represent higher risk. Risk factors are also visualized via a thematic map in which users can discover spatial trends. More specifically, a choropleth map is used to aggregate risk factor data at the county level and color the regions in different shades to represent the extent of risk (WHO, Tools for making good data visualizations: the art of charting, 2021). Choropleth maps were chosen because they are easy to read and can be understood by various audiences (R.W., C.A., & Nall J., 2021).

To visualize trends of COVID-19 from the beginning of the pandemic in early 2020 to present day, county and state level, weekly aggregated, timeseries bar plots of COVID-19 cases

and deaths are presented (**Figure 5**). Weekly aggregations are found to be ideal because day aggregations tend to produce plots that are not easy to interpret and monthly aggregations

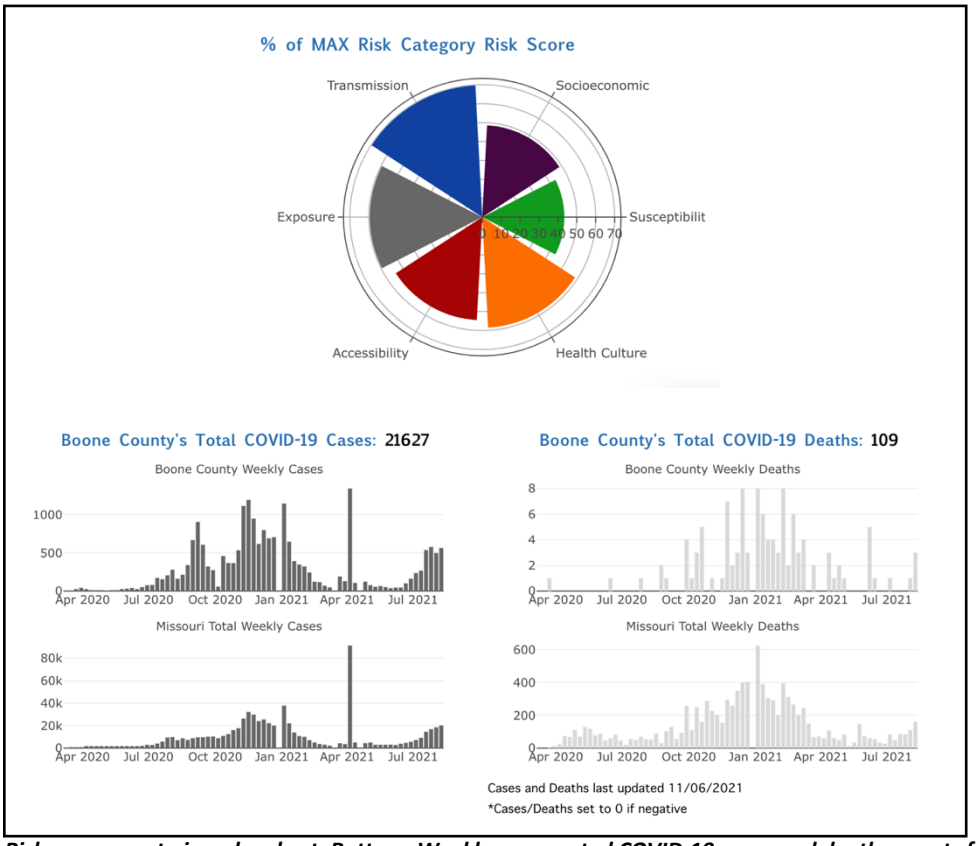


Figure 5: Top: Risk assessment pie radar chart; Bottom: Weekly aggregated COVID-19 cases and deaths counts for the state and selected county.

may lose noticeable patterns and are imprecise due to the varying number of days in a month (Sumner, 2018). Users can monitor COVID-19 counts when there are recurrent outbreaks, track how pandemic mitigation measures impact case/death count when implemented, and compare how a county may have contributed to state outbreaks. Using this feature, users can also explore case/death trends of counties with specific risk profiles.

A radar pie chart (also known as a wind-rose plot) with max-normalized risk category scores as slices was selected to convey the risk assessment of a county. At a quick glance, users can see which categories of risk are most prevalent in a county. The risk category color scheme

was applied in this visual to allow users to interpret the risk profile by associating a color to a type of risk. An individual slice tells a story of how a specific type of risk compares with the county with the max risk value; if a slice has a value of 100%, then the selected county would be the county (or one of the counties) with the highest risk score in that category.

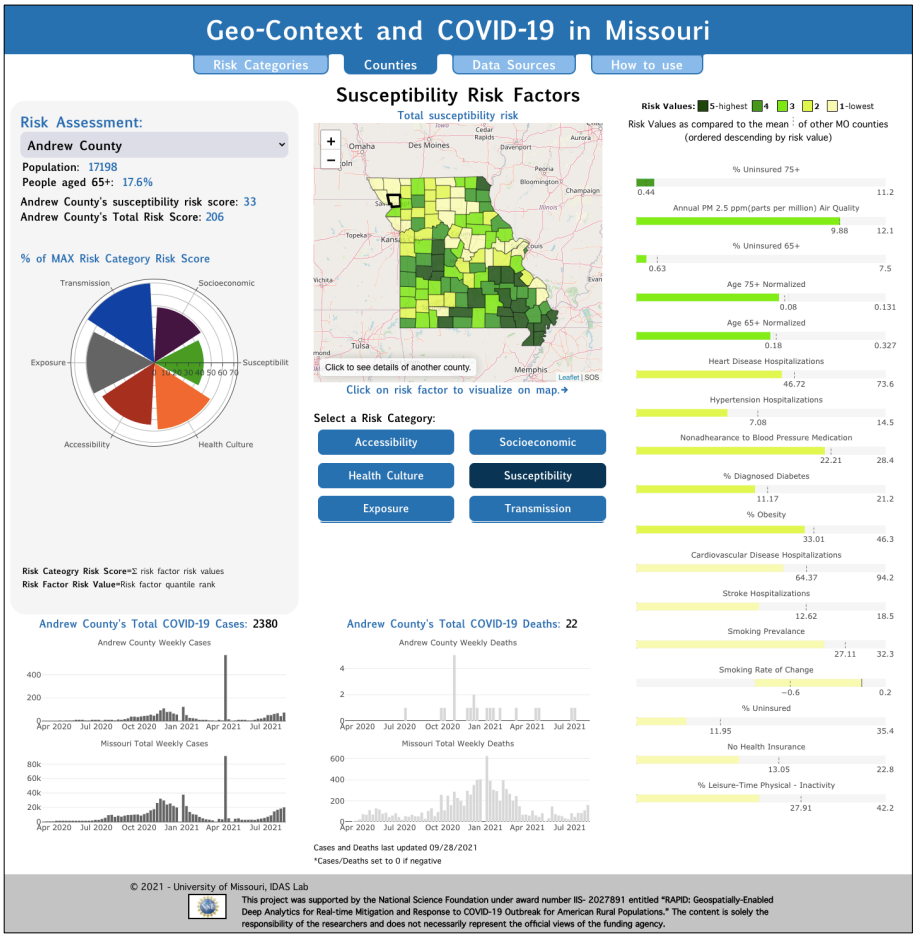


Figure 6: Counties Dashboard

The *Counties* Dashboard can be seen in **Figure 6.** Users can select a county using the drop-down menu in the risk assessment module in the top left or by directly clicking on the map. Selecting a county outlines its location on the map and triggers a county-specific data change throughout the dashboard. Upon entering the webpage, the susceptibility risk factor is chosen as indicated by the title located in the top center of the dashboard and the darkened

risk category button. When a user selects a new risk category (by clicking on the risk factor button), the title, color scheme, and set of risk factors change. Before risk factors are clicked on and visualized on the map, the risk category score of each county is visualized. When a user selects a risk factor, the map and title above the map will change to the selected risk factor. Hovering over a visual will display the value that the plot represents. For example, hovering over the different slices of the risk assessment radar chart will display the % of max risk category score value. The COVID-19 cases and death plots also have an additional feature where users can zoom into specific date ranges.

Using this dashboard, researchers can conduct initial exploratory analysis of risk factors that can be considered for use as features in statistical models or find spatial trends in rural counties that have not been discovered in existing literature promoting new research initiatives. Healthcare planners and employees can gain insight into the vulnerabilities of their county and surrounding counties in order to prepare for when there are outbreaks of COVID-19 due to possible variants. Policymakers at the local level can learn about deficiencies in their districts and move more resources to vulnerable communities.

3.4. **Risk Categories Dashboard**

The “Risk Categories” dashboard lets users customize the risk assessment by choosing which risk categories to include in the risk score calculation. The objective of this dashboard is for users to explore relationships between different types of risk and how rural or urban a county is. The main feature of this dashboard is the choropleth map displaying the customized risk score across all Missouri counties **(Figure 7).** The color scale ranges from cooler tones representing decreasing risk to warmer tones representing increasing risk. When applying the

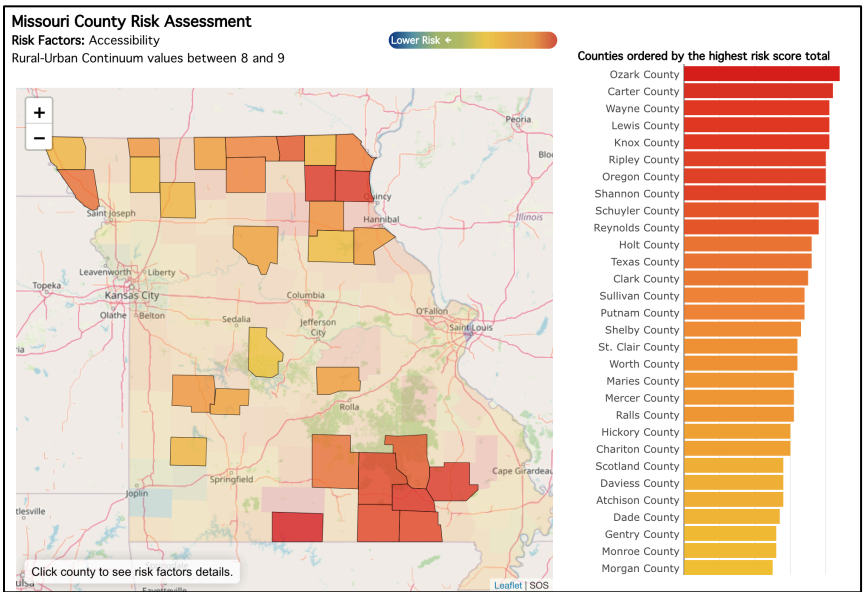


Figure 7: Customized risk assessment visualized using choropleth map and bar plot

rural urban continuum filter, counties that do not fall in the selected filter range are set to a low opacity, becoming less pronounced; their degree of risk can still slightly be seen so that comparisons can be made to the counties that do not get filtered out. Clusters of counties that meet filter requirements are easily seen. A bar plot compliments the map by sorting counties by highest risk score total.

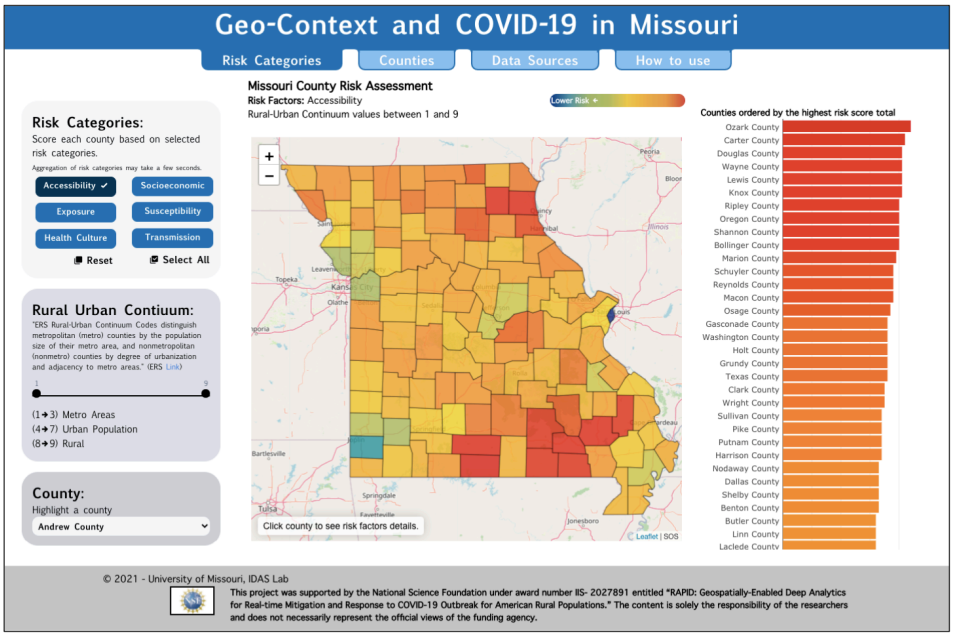


Figure 8: Risk Categories dashboard

The *Risk Categories* Dashboard Is seen in **Figure 8.** Using top-left modules, users can select which risk categories they would like to include in their customized risk assessment. When a category is selected the button becomes a darker shade of blue and a white check mark appears. Users have the option to select all risk categories using the "Select All" button. To easily start over without having to de-select chosen buttons, users can click on the "Reset" button. The left-middle module is where the Rural Urban Continuum filter is set. A definition is provided for further context, along with the ranges that distinguishes rural and urban counties. Users slide both ends of the sliders to select a preferred range. Aggregations and filters are automatically applied when a change is made. The last component can be used to outline counties on the map so that users can easily locate a county of interest. A summary of the chosen risk categories and the range of the rural urban continuum filter is displayed above the map. Users can click a county on the map to be redirected to the Counties dashboard for further exploration.

There is a lack of research when it comes to Missouri rural counties and COVID-19. *Risk Categories* give users a platform for understanding the correlation between rurality and COVID-19. Policy makers at a state level can use this dashboard to visualize how risk is distributed throughout the different regions in Missouri and also between the rural and urban counties; allowing them to make more informed decisions about public health.

3.5. Supporting web pages

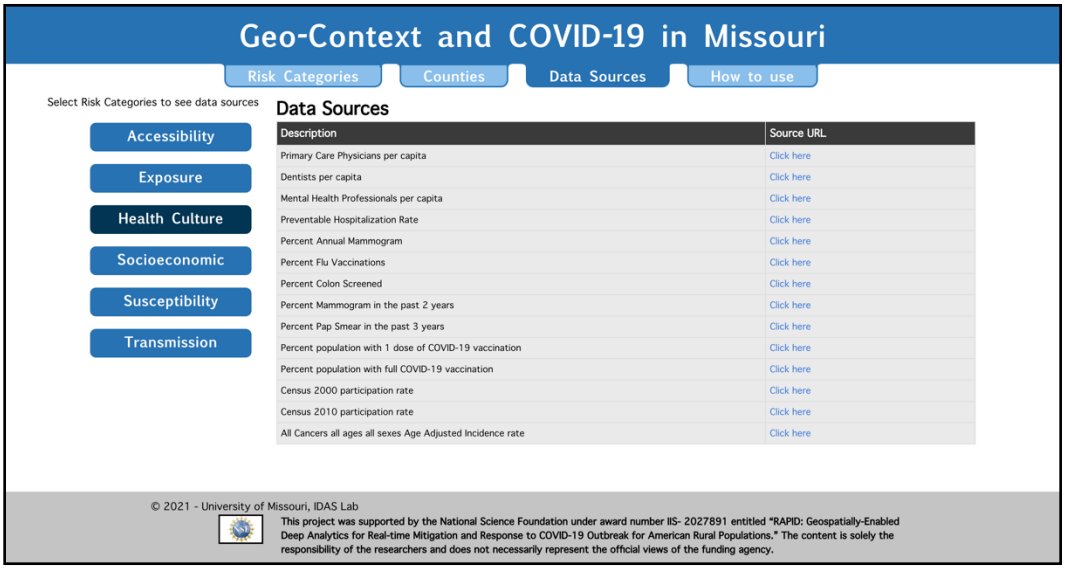


Figure 9: Data Sources Tab

The *Data Sources* webpage (**Figure 9**) provides users with links to all source websites where risk factors were extracted. Data that creates this webpage is found in the ***covid_sources*** collection. When a risk factor is updated, added, or removed, the change will be reflected on this page so that users can always have access to updated data sources. This is a great resource for researchers performing initial data collection.

The *How to use* webpage gives users an overview of the risk assessment. Contained in in this webpage are descriptions of each risk category and an explanation of how the risk values, risk category scores, and total risk scores are derived. Selecting the "Risk Categories" or "Counties" tab on the left displays a use guide for the selected dashboard. How to use guides can be seen in **Figure 14** and **Figure 15** which will be further explained in the following section.

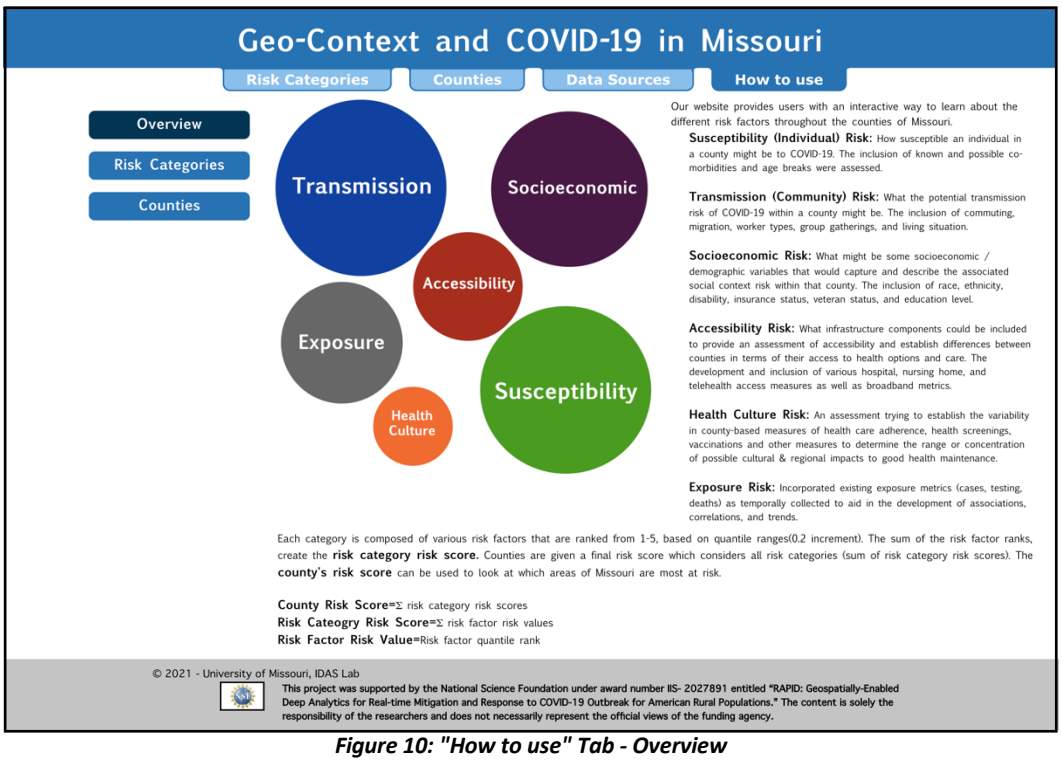


Figure 10: "How to use" Tab - Overview

4. Usability Evaluation Methods

A usability study was constructed based on the evaluation scenarios suggested by A *Framework for Evaluating Dashboards in Healthcare* (Zhuang, Concannon, & Manley, 2020) which include task performance, interaction workflow, perceived engagement, behavior change, and system implementation.

An evaluation web application was developed to offer users a simple way to participate in the usability study at their own leisure and the location of their choice. The application prompts users through different parts of the evaluation while collecting and storing data in an evaluation database. This ensures that the experience across users is consistent which reduces bias and eliminates any stress that may have resulted from a procedure with disjointed steps. The application flow is seen below in **Figure 11**. Users are asked to complete two types of

evaluations for each dashboard: task analysis and a heuristic survey, which are explained further below.

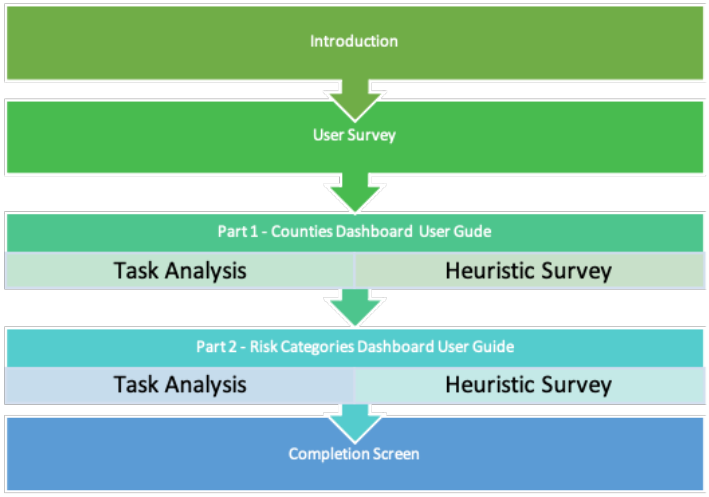


Figure 11: Evaluation flow

When evaluators opened the application, they were taken to an introductory webpage where they were shown risk category descriptions and information about the procedure (**Figure 12**). The expected duration of the evaluation was 25 minutes at most. During the evaluation, no user identifiers linking data to a user's identity were collected. Instead, a UUID (universal unique identifier) was generated using the "uuid" Python package to link task hover/click data and survey answers to one "session". To keep sessions anonymous, the identifier was not shared with the evaluator; thus, there is no save function and evaluations must be completed at one time. Although that is the case, the evaluation is set up to send data to the database after each type of analysis; this helps capture individual task analysis and survey answers regardless of whether all portions of the evaluation are completed.

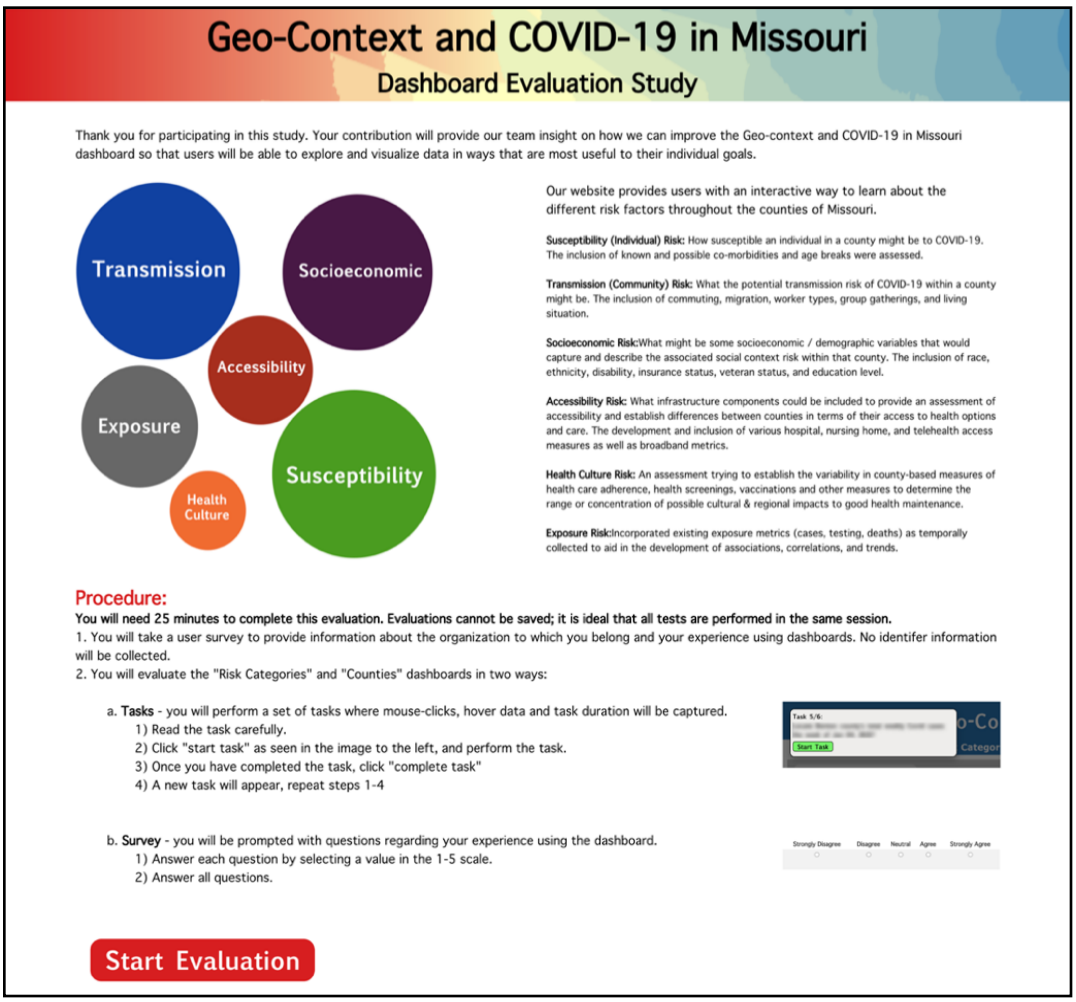


Figure 12: Evaluation - Introduction

When users clicked the “Start Evaluation” button they were directed to the “user’s survey” (**Figure 13**). Because identifiers are not collected, this survey gathers general information about the stakeholder, their experience using dashboards, and their current internet speed. Slow internet speeds can negatively impact the user’s experience and is a factor that may need to be considered; however, internet speed is collected for information only.

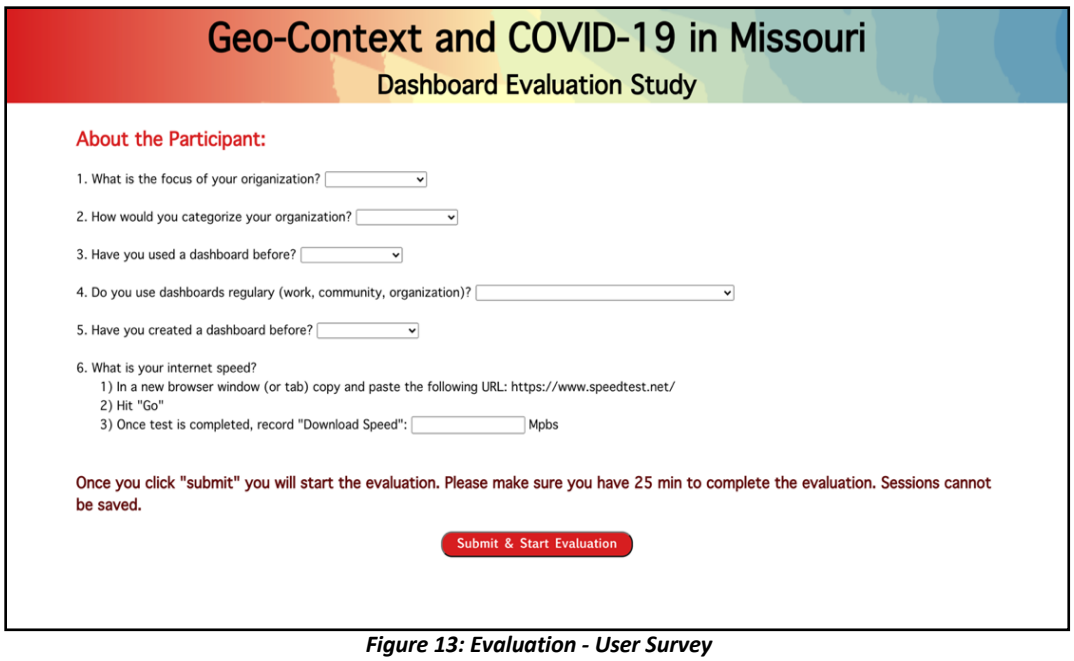


Figure 13: Evaluation - User Survey

Following the user survey, participants evaluated both *Counties* and *Risk Categories* dashboards in two parts. Each part consists of three sections:

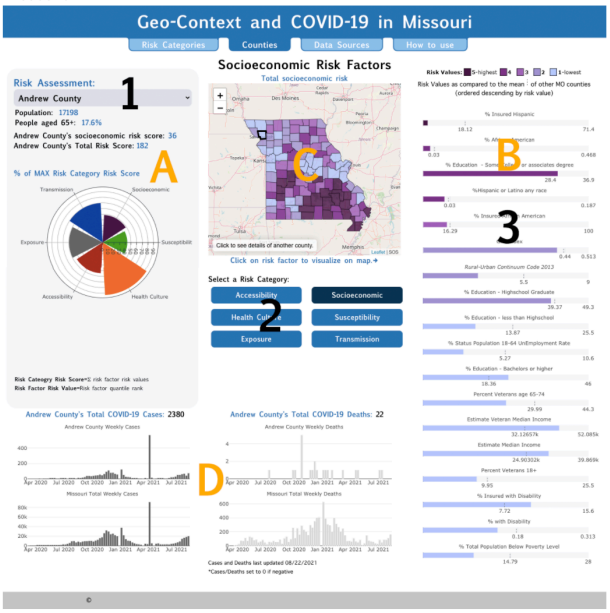
- **How to use** – evaluators were provided with guides on how to use each dashboard prior to the evaluation
- **Task Analysis** – evaluators were prompted to perform tasks related to the main functionality of each dashboard
- **Survey Evaluation** – evaluators answered survey questions regarding their experience using the dashboards

4.1. "How to use" Guides

Prior to each dashboard's evaluation, participants were provided with "how to use" guides, seen in **Figure 14** and **Figure 15.** The navigation portion of each guide provides information on how to perform the main functions of the dashboard. The "features of dashboard" section gives a description of each main component.

How to use the Counties Dashboard

The "Counties" dashboard allows users to dive-in to different risk categories and learn about the magnitude of risk factors in the individual counties of Missouri.



How to navigate dashboard:

1) Select a county
2) Select a Risk Category
3) Click on Risk Factors to geo-spatially visualize

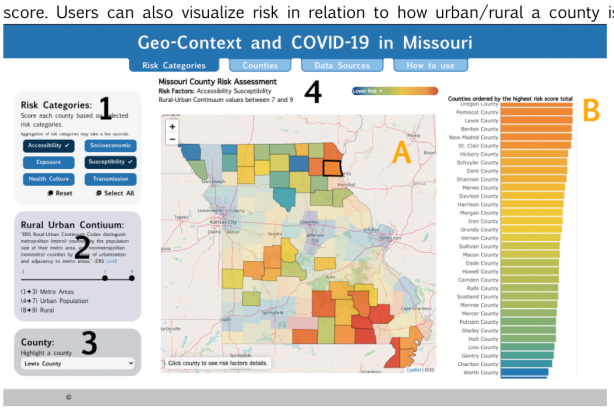
Features of dashboard:

A) A COVID-19 risk assessment of each county which includes a risk score per category (sum of all risk factor values) and a total risk score (sum of all risk category scores). The wind rose plot reports the proportion of each risk category as compared to the max value of all Missouri counties.
B) Risk factor bar plot that compares a county's value to the average and max of all Missouri counties.
C) A risk factor choropleth map.
D) COVID-19 weekly Cases and Deaths (updated daily)

Figure 14: Web Evaluation - Counties Dashboard "How to use" Guide

How to use the Risk Categories Dashboard

The "Risk Categories" dashboard lets users create a customized risk assessment by selecting which risk categories they'd like to include in the county risk score. Users can also visualize risk in relation to how urban/rural a county is.



How to navigate dashboard:

1) Select risk categories to be included in the county risk score
2) Filter counties based on the rural-urban continuum (rural VS urban)
3) Highlight a county of interest (optional)
4) Review filter selections and legend

Features of dashboard:

A) Choropleth map of county risk scores (based on selected risk categories).
B) B) Bar plot ordered by highest county risk total (counties that do not fit within filter specifications are not included in this plot).

Figure 15: Web Evaluation - Risk Categories dashboard "How to use" guide

4.2. Task Analysis

To evaluate **task performance**, how effective each dashboard is with regard to the performance of tasks (Zhuang, Concannon, & Manley, 2020)**,** the core objective of each dashboard was broken down into individual tasks that evaluators were asked to complete (refer to **Table 5**)**.** The main functions of the *Counties* dashboard enable users to navigate among

counties and explore risk factors that belong to the different risk categories. Task CT01 tests users' ability to select a county using either the drop-down menu or directly from the map and if they are able to switch between risk categories. Task CT02 examines if users can visualize different risk factors on the map by clicking the bar plot or title of the risk factor. If CT01 is successfully completed, users will have the transmission risk category selected where the "% Households Nonfamily with one or more 65+ Living Alone" risk factor is found which is used in CT02. Task CT03 is more complicated because users must determine which risk category "Preventable Hospitalization Rate" belongs to. This task asses how well users can find risk factors based on their understanding of what factors are found in each risk category.

The main objective of the *Risk Categories* dashboard is to select risk categories of interest, generate a customized risk score from the categories, and apply a rural-urban continuum filter to see if there are relationships between risk and how rural or urban a county is. Task RCT01 gauges a user's understanding of aggregating risk categories by selecting multiple risk categories and highlighting a county on the map using the drop-down menu in the highlight module. Task RCT02 tests if users can find and implement the rural urban continuum filter.

Users were allowed an exploration session to use the dashboard to their liking and not be constrained to task prompts. Data about their exploration was collected for information purposes only.

Table 5: Task Analysis Prompts

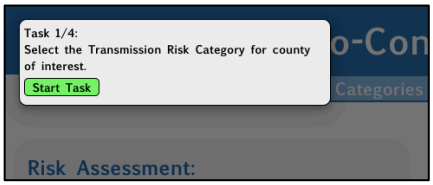
Counties Dashboard	
Task ID	**Task**
CT01	Select the Transmission Risk Category for county of interest.
CT02	Visualize the "% Households Nonfamily with one or more 65+ Living Alone" Risk factor on the map.
CT03	Find and visualize the "Preventable Hospitalization Rate" Risk factor on the map.
CT_EX	User Exploration - **What would you like to learn from this dashboard?**
Risk Categories Dashboard	
Task ID	**Task**
RCT01	Generate risk assessment including Susceptibility, Transmission, and Socioeconomic risk categories and highlight county of choice.
RCT02	Generate risk assessment for all risk factors and include only counties that fall in Rural Urban Continuum spectrum between 1 and 3.
RCT_EX	User Exploration- **What would you like to learn from this dashboard?**

Users were allotted unlimited time to read the task description prior to starting the task. When they were ready to begin the task, they clicked the "Start Task" button. When they determined that the task was completed, they clicked the "Complete Task" button. While attempting each task, the following data was collected and linked a user's UUID: time stamps of when the "start task" and "end task" button was clicked and timestamps of click/hover events for each component (identified by a component ID). An example of how this data was stored in the database can be seen in **Table 6**..

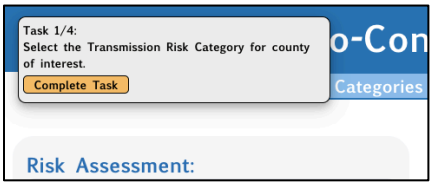
Three metrics will be calculated from the task analysis data: first click success rate, overall success rate, and average time to successfully complete a task (R.W., C.A., & Nall J., 2009). The first click analysis will be used to test how intuitive a task is based on which element is clicked first. Each task tests main functionalities of the dashboards, whether users often select elements that are not related to the objective, then how to perform a certain function may not be clear. Success rate of a task measures whether users are able to complete a task

Table 6: Evaluation: Task Analysis; a) Task prompt prior to started task b) Task prompt during task c) How task data is stored in evaluation dashboard

a) Prompt Not Started– Start Task Button



b) Prompt started – Complete Task



c) Example of how data is stored in database

userID	taskID	event	timestamp
bf749f50-b	CT01	start	2021-10-07 11:49:04
bf749f50-b	CT01	transmission_buttonclick	2021-10-07 11:49:19
bf749f50-b	CT01	end	2021-10-07 11:49:38

(R.W., C.A., & Nall J., 2009). The first click analysis will be used to test how intuitive a task is based on which element is clicked first. Each task tests main functionalities of the dashboards, whether users often select elements that are not related to the objective, then how to perform a certain function may not be clear. Success rate of a task measures whether users are able to complete a task successfully. If a majority of users cannot complete a task, then this is an indication that more instruction needs to be provided or a re-design of the intended functionality is necessary. The average time to successfully complete a task can be used to judge whether users can efficiently complete a function in a practical amount of time (R.W., C.A., & Nall J., 2009)

4.3. Heuristic Evaluation

Survey questions were created to assess user perspectives using the dashboard (**perceived engagement**), the long term influences each dashboard may have on the user (**behavior change**), and whether the implementation of the dashboard successfully accomplished its intended goal (**system implementation**) (Zhuang, Concannon, & Manley, 2020). Questions were ranked using the scale below:

Table 7: Evaluation Survey Scale

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

4.3.1. Perceived Engagement

To measure perceived engagement, questions were created based on six of Nielson's usability heuristics for user interface design (Nielsen, 1994): visibility of system status, match between the system and the real world, consistency and standards, recognition rather than recall, flexibility and efficiency of use, and aesthetic and minimalistic design.

The *visibility of a system* principle states that a design should provide feedback after every interaction to inform users about the status of the system (Nielsen, 1994). On the *Counties* dashboard users can identify which county, risk category, and risk factor is selected in various ways. The selected county can be seen in multiple titles throughout the dashboard, outlined on the map, and above the COVID-19 cases and death plots. The risk category that is selected is visible in two places: the title below the navigation bar and the darkened risk factor button. Selected risk factors will appear in the title above the map. On the *Risk Categories* dashboard, users can identify which risk categories are selected in three ways: the color of the risk category button is darker if selected, a check mark appears on the same button if selected,

and the risk factors that are chosen are added to the summary subtitle below the "Missouri County Risk Assessment" title. The Rural Urban Continuum filter has a similar design. When applied, the range is displayed in the summary subtitle and can be seen in the rural urban continuum component via the slider. Lastly, when a county is highlighted, the county name is displayed in the drop-down menu and also outlined on the map. Using this heuristic, survey questions were created to test whether these indicators were sufficient to keep users informed of selected factors.

The *match between the system and the real-world* principle suggests that a system should be designed in a way such that words, phrases, and concepts are familiar to the user (Nielsen, 1994). The most important features of the website are the risk factors that create the risk assessment and how the risk assessment is derived. Equations can be found in the risk assessment module on the *Counties* dashboard. Evaluators are tested on their understanding of the three components that create the risk assessment score and risk factor categorization. To successfully use each dashboard, users are asked to rank their understanding of the following four visuals on the *Counties* dashboard and the rural urban continuum component of the *Risk Categories* dashboard:

- **Risk factor bar plot** - used to compare risk factor values to the average, min, and max values found in Missouri
- **The Choropleth map** - display the spread of risk values (high and low) throughout Missouri counties
- **The risk assessment radar pie chart** - displays a county's risk profile
- **Case/deaths time series plots** - presents COVID-19 trends over time
- **Rural urban continuum classification** - distinguishes how rural or urban a county is

The *consistency and standards* principle explains that there should be consistency amongst elements throughout the website (Nielsen, 1994). The risk factor buttons on both dashboards were created to have the same color and similar functionality. When selected, the buttons change color to a dark blue and a risk category is selected. Both dashboards also have a county-drop menu signified by an upside-down triangle which is universal to drop-down menus. Users are asked to rate the consistency of the design and functionality between the two dashboards during the *Risk Categories* survey evaluation. On the *Counties* dashboard, each risk category has a color scheme to help users associate risk to a specific risk category. Users' perception of how consistent the risk category color schemes are across components or how well they associate risk to a color is gauged.

According to the *Flexibility and efficiency of use* principle a design should offer users the ability to use shortcuts and have customization (Nielsen, 1994). On the *Counties* dashboard, users can select a county by using the drop-down menu or clicking a county on the map. Although the option is labeled, a survey question is created to examine whether users were aware that the map shortcut was available. The *Risk Categories* dashboard gives users full customization when generating a risk assessment and also offers a "select all" and "reset" function to prevent users from being required to de-select or select all risk categories manually.

The *Recognition rather than recall* principle proposes that an interface should be designed with all information required for a user to successfully navigate and use the system (Nielsen, 1994). "How to use" guides were created for each dashboard and will be presented to evaluators prior to completing each survey. The *Counties* dashboard has descriptions that directs users to select a risk category and how to visualize a risk factor on the map. The *Risk*

Categories dashboard contains instructions that direct users to score counties through aggregation and to select a county via the drop-down menu to highlight on the map. Survey questions were created to test how helpful the prompts were and to determine whether users were able to perform important functionalities such as selecting risk factors, generating the risk assessment and locating counties and important information easily.

The *Aesthetic and minimalistic design* principle recommends that a design should not contain information that is not relevant to goal of the interface (Nielsen, 1994). Evaluators are asked to rate the relationship between the data displayed on each dashboard and COVID-19.

4.3.2. Behavior Change and System Implementation

Because the long-term effects of using the website cannot be measured directly without conducting future surveys, behavior change was measured by asking evaluators about each dashboard's immediate influence. The *Counties* dashboard contains 87 risk factors for users to explore and learn about. After using this dashboard, evaluators may be exposed to risk factors that they did not know about previously. The *Risk Categories* dashboard allows users to look at risk from many different customized risk perspectives. This may be the first time that evaluators will be able to look at different combinations of risk throughout the counties of Missouri. Evaluators learning something new from either dashboard can be considered an immediate effect of using the website. A future behavior change would be referencing both dashboards again at a different time. After using both dashboards, participants were asked about their likelihood of referring to each dashboard again and also if they learned something new.

To test the success of *system implementation* evaluators were asked to rank the ease of use of each component and the usefulness of visualizations and guides.

4.4. Recruitment

The following organizations were contacted during recruitment via email with an explanation of the study and a recruitment infographic for sharing purposes:

- 38 planning committees that work with state/regional/county initiatives such as Missouri Rural Health Association, Missouri Public Health Association, Missouri Health Care Association, and Missouri regional planning commission.
- The University of Missouri school of Medicine

Volunteers were asked to contact the study researcher if they had interest in participating in the study. After contact was established, the volunteers were sent a link to an evaluation web application and a consent form. To be eligible to participate in the research the inclusion criteria must be met:

1. 18 years or older
2. A member or employee of an organization that is involved with research or planning for healthcare and community initiatives at the state and/or regional level

5. Results

5.1. Study Limitations

One major limitation of this study was the lack of volunteers to perform the evaluation, specifically from the state/regional/county initiative planning groups (labeled as Research Government under the participants section below). The absence of evaluators from this field limits our understanding of how useful this stakeholder group may perceive the presented data on each dashboard for their field of work.

5.2. Participants

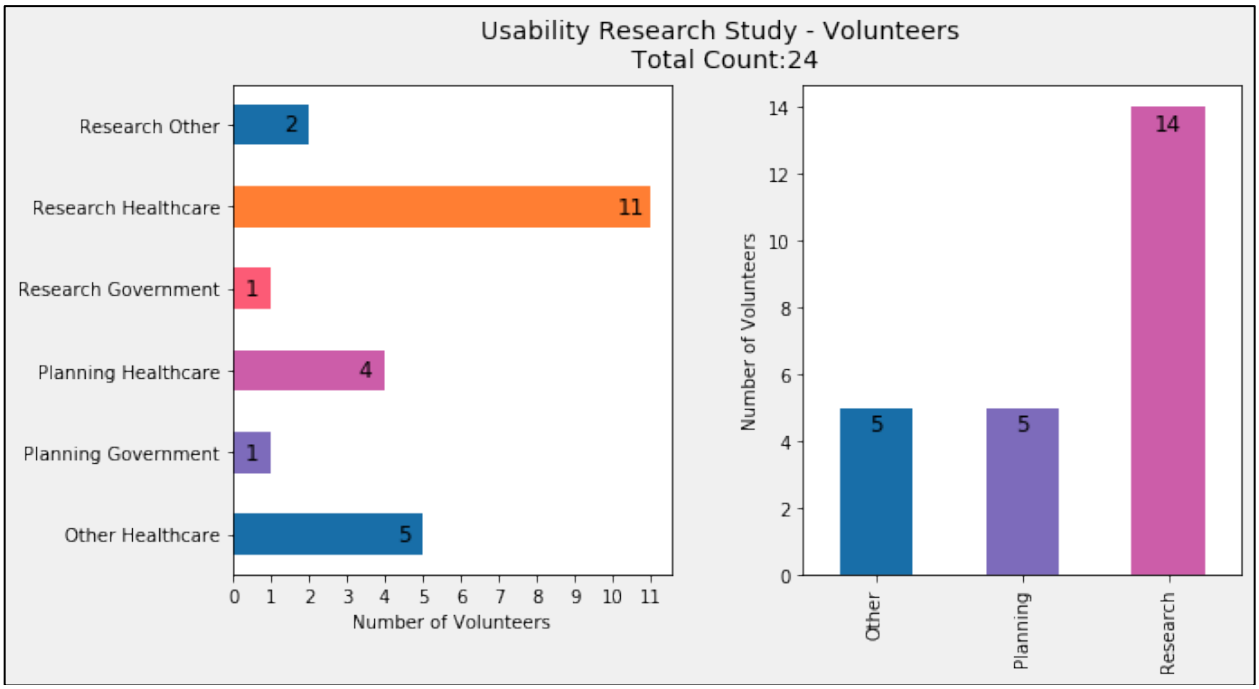


Figure 16: Volunteer Breakdown

A total of 24 volunteers participated in the website evaluation study. A breakdown of the individual categories can be seen in **Figure 16**; 58% are research stakeholders (14/24 volunteers) ,21% (5/24 volunteers) are planning stakeholders and 21% (5/24 volunteers) are "other" which consist of individuals that work in healthcare but do not classify themselves as researchers or planners. One volunteer dropped out and only completed the counties evaluation; this volunteer identified as a Healthcare researcher.

Participants were asked about their experience using and creating dashboards; evaluators who have not used a dashboard before may not have built up intuition about how to use a dashboard making it harder for them to adjust to a new interface, results are seen in **Figure 17** below.

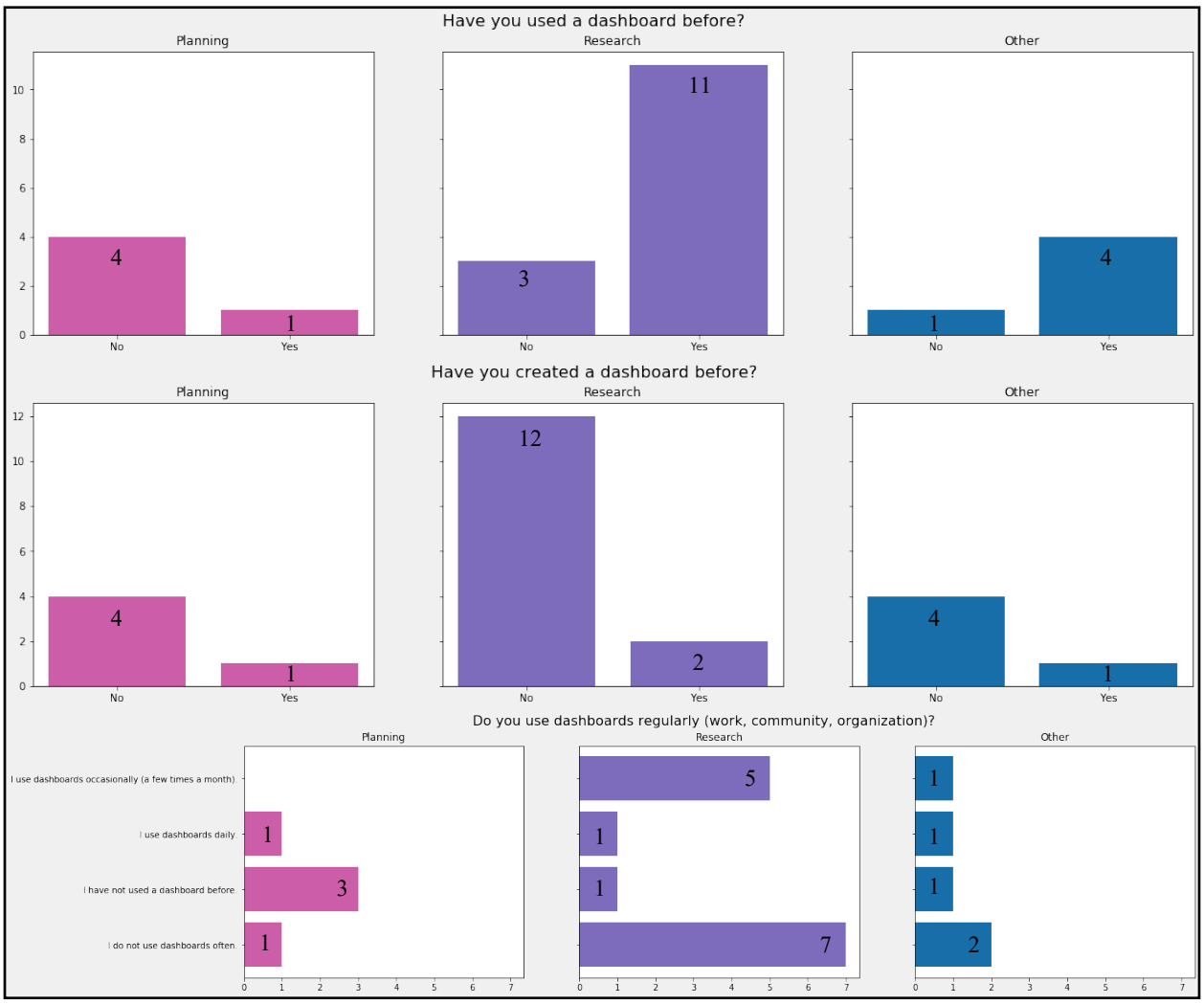


Figure 17: Dashboard Experience by stakeholder group

The planning stakeholder group is primarily made up of volunteers who have not used or created a dashboard before. One individual from this group, who works in healthcare, has created a dashboard and uses dashboards daily. A majority of volunteers from the research stakeholder group have used a dashboard before but mostly have not created a dashboard; 5/14 volunteers (36%) use dashboards occasionally, 1/14 (7%) use dashboards daily, and 8/14 (57%) do not use dashboards often or have not used a dashboard before. All but one volunteer from the "other" stakeholder group, have used a dashboard, but only 2/5 use them occasionally or daily. Overall, 16/24 volunteers (67%) have experience using a dashboard and only 4/24

volunteers (17%) have created a dashboard. Of those that have used a dashboard, 3/16 volunteers (19%) use dashboard's daily and 6/16 volunteers (38%) use dashboard occasionally.

Because there is overhead with a dynamic dashboard, internet speed was captured per volunteer to take into consideration any additional factors that may impact user experience.

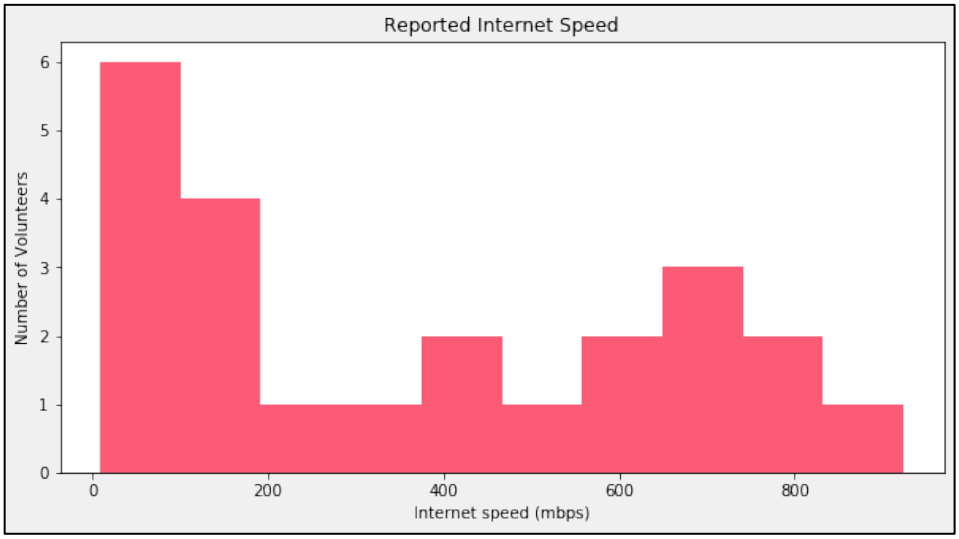


Figure 18: Reported Internet Speed

The minimum internet speed reported was 8.70mpbs and the mean was 374mbps. One user did not answer this question. All reported internet speeds were adequate for users to use the dashboard without significant impacts to their experience.

5.3. Counties Dashboard – Task Results

During the task evaluation, if a participant refreshed the browser or hit the back button, the task analysis would restart and could performed more than once. However, event data was sent to the evaluation database when the action was completed and thus all actions were captured. To prevent biased results, repeated evaluations were aggregated and all actions were considered. Users who did not attempt the task evaluation (click activity count = 0) were removed from the final results. For all task evaluations, results are reported per stakeholder

group and overall. There were not enough participants per group to compare success rates with high confidence; this reported data is for additional information.

Table 8:Counties dashboard, CT01 Results

Counties Dashboard: Task Evaluation 1 (CT01) Select the Transmission Risk Category for county of interest.			
Volunteer type	**First Click Success Rate**	**Average/Median Time for successful completion**	**Success rate**
Research n=14	79%	1 min 38 sec / 39 sec	86%
Planning n=4	50%	22 sec/ 22 sec	50%
Other n=5	100%	24 sec/ 22 sec	60%
All n=23	78%	1 min 15 sec/ 28 sec	74%

During the Counties dashboard: task evaluation 1 (CT01), participants were asked to select the transmission risk category for a county of interest. There are two "ideal" paths, composed of 2 clicks, users can take to complete this task: 1) select a county of interest from the map or from county drop-down menu, and then click the transmission risk category button or 2) select the transmission risk category button and then select a county of interest from the map or county drop-down menu. The success rate of CT01 was 74%. On average, this task was successfully completed in 1 min and 15 seconds; the median was 28 seconds. Of the six participants that did not complete the task, 4 selected a different risk category, 1 clicked on the radar chart (possibly clicking on the transmission risk slice) and one user just selected a county. A successful first click was considered as a click on the transmission risk button or a click choosing a county of interest. 83% of those who had an acceptable first click, successfully completed the task; 2 participants completed task despite failing the first click test.

Table 9: Counties dashboard, CT02 Results

Counties Dashboard: Task Evaluation 2 (CT02) Visualize the "% Households Nonfamily with one or more 65+ Living Alone" Risk factor on the map.			
Volunteer type	**First Click Success rate**	**Average/Median Time for successful completion**	**Success rate**
Research n=12	42%	1 min 10 sec/ 12 sec	58%
Planning n=3	33%	21 sec/ 21 sec	33%
Other n=5	42%	1 min 22 sec/ 17 sec	60%
All n=20	35%	1 min 9 sec/ 17 sec	55%

Counties dashboard: task evaluation 2 (CT02), asked participants to visualize the Transmission risk factor "% Households Non-Family with one or more 65+ Living Alone" on the map. If users successfully completed CT01, only one click on the risk factor bar plot would be needed to finish CT02. Users who did not complete task 1 would need to determine the risk category where the factor would be found, select the category, and then find the risk factor. One common error occurred during this analysis and that was the selection of another risk factor with a similar name "% Households Non-Family with one or more 65+". Because these factors have the same description except for "Living Alone", participants might have mistakenly thought that was the right factor. Thus, both factors are accepted. The success rate of CT02 was 55% with an average successful completion time of 1 min and 9 seconds and a median time of 17 seconds. Only participants who completed task 1 correctly went on to successfully complete task 2. Of the 9 that did not correctly complete this task, 6 clicked on different risk categories but did not select any risk factors, 3 clicked on the radar chart slices, and 1 selected the wrong factor "Age 65+ Normalized" found under the susceptibility risk category. It is possible that those who clicked on different risk categories were looking for the risk factor and/or did not understand how to

visualize a factor on the map. A first click was considered successful if a user clicked on either of the two acceptable risk factors (mentioned above) or the transmission risk factor (for those who did not complete task 1 correctly). 100% of participants who successfully completed the first task, found the correct risk factor and visualized it on the map.

Table 10: Counties dashboard, CT03 Results

Counties Dashboard: Task Evaluation 3 Find and visualize the "Preventable Hospitalization Rate" Risk factor on the map.			
Volunteer type	**First Click Success rate**	**Average/Median Time for successful completion**	**Success rate**
Research n=11	45%	1 min 3 sec/ 54 sec	64%
Planning n=4	0%	N/A	0%
Other n=5	40%	2 min 59 sec/ 2 min 59 sec	40%
All n=20	35%	1 min 22 sec/ 1 min 18 sec	45%

Counties dashboard: task evaluation 3 (CT03), tested a user's ability to find a risk factor that belonged to a different risk category (not already selected from CT01) based on the users understanding of what each risk category might contain. This task had a success rate of 45% with an average successful completion time of 1 min 22 seconds; the median time was not significantly lower like CT01 and CT02 indicating that users consistently took longer to complete this task. The "preventable hospitalization rate" factor is found under the "health culture" risk category; thus, to complete this task, at minimum, a user would need to first click the "health culture" risk category button and then the risk factor. 35% of users successfully selected the health culture button first (71% of those who did, completed CT03 successfully). Those that did not get the first click correct, but completed CT03 correctly, selected a different risk category (or several different risk categories) before clicking on health culture and finding the

"Preventable Hospitalization rate". 7 out of 11 participants who did not complete CT03 did select the health culture category, but did not find the risk factor.

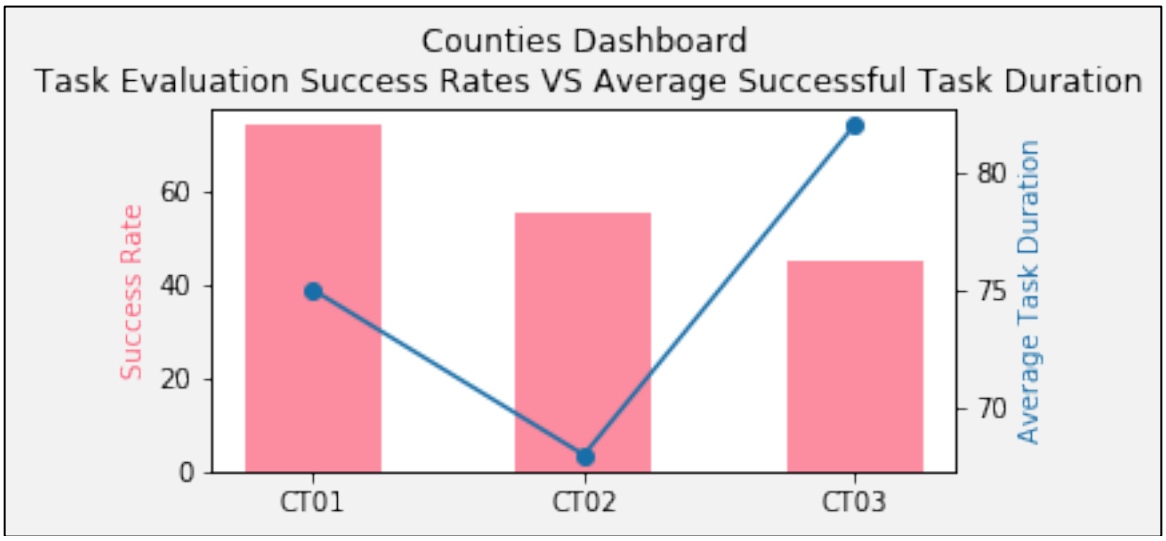


Figure 19: Counties Dashboard Task Evaluation Summary

The success rate and average successful task duration of the *Counties* dashboard task evaluations is displayed in the plot above (**Figure 19**). Subsequent tasks were designed to build on the last, growing slightly in difficultly, which is consistent with the reported success rates. During CT01, the majority of participants were able to find the transmission risk category button which is the foundation of being able to browse different risk factors. CT02 introduced the risk factor concept which was in a different format of a traditional button and involved users having to locate the risk factor from a list to visualize on the map. CT03 was more difficult because it involved users using both skills learned from CT01 and CT02 and finding a risk factor based on the given categories. The average successful duration of CT01 is longer than CT02, but less than CT03. Because users are first exposed to the dashboard during the first task, it is likely additional time was used to become familiar with the different components resulting in a slightly longer task duration compared to CT02. CT02 did not require users to switch risk categories to find the risk factor (if CT01 was successful). This is seen with the decrease in task

duration of CT02. Lastly, due to CT03's difficulty, the task duration is expected to be longer compared to CT01 and CT02.

5.4. Counties Dashboard – Survey Results

. There were not enough participants per group to definitively compare usability between the groups; however, to gain additional insight, survey results are reported per stakeholder group and overall. Any questions that were left unanswered were removed from the reported average and marked with an asterisk (*). Six survey questions were left unanswered from 4 evaluators of the Counties Dashboard.

5.4.1. Perceived Engagement

Table 11: Visibility of System – Counties Dashboard Evaluation Results

Survey Question	Research (n=14)	Planning (n=5)	Other (n=5)	All (n=24)
I was able to identify which county was selected and where it is located in Missouri.	4.2	4.8	4.6	**4.4**
I was able to identify which risk category was selected.	4.3	4.8	4.6	**4.5**
I was able to identify which risk factor was visualized on the map.	3.7	4.8	4.8*	**4.1***
Average	**4.1**	**4.8**	**4.6**	**4.3**

Overall, the **visibility of system** evaluation questions has an average score of 4.3, where researchers had the lowest score at 4.1. Researchers had issues identifying which risk factor was visualized on the map, whereas planning and the "other" healthcare stakeholder group did not. The majority of evaluators were able to find which county and risk category was selected; these features likely were more easily identified due to their status being displayed in multiple locations compared to the risk factor which was only displayed as a title above the map.

Table 12: Match between the system and the real world –Counties Dashboard Evaluation Results

Survey Question	Research (n=14)	Planning (n=5)	Other (n=5)	All (n=24)
The spread of risk values (high risk/ low risk) amongst Missouri counties was clearly seen on the map.	4.2*	4.6	4.0	**4.3***
I was able to see how a specific county's risk factor value compared to the average and maximum value of all Missouri counties.	3.9	4.6	4.2	**4.1**
I could find how covid cases and deaths trended throughout time for all of Missouri and in different Missouri counties.	4.1	4.4	4.0	**4.2**
Using the wind-rose plot, I was able to see the proportion of risk categories in a Missouri County compared to the maximum risk score.	3.6	4.2	4.4	**3.9**
The risk factors were related to the risk category they were grouped within.	4.1	4.4	3.5*	**4.1***
I understand how the risk category risk score was derived.	2.9	4.0	3.8	**3.3**
I understand how the total risk score was derived.	2.8	4.0	4.0	**3.3**
I understand how each risk assessment is generated.	2.9	4.0	4.2	**3.4**
I understand how risk factors are given a "risk value"	3.1	3.8	4.0	**3.5**
Average	**3.5**	**4.2**	**4.0**	**3.8**

The **match between the system and the real-world** questions had an average score of 3.8. Researchers reported having a poor understanding of how all scores of the risk assessment were derived, whereas, the calculation of risk values of risk factors and risk category risk scores posed slight issues for planners and the "other" stakeholder group respectively. While both planners and researchers found that the risk factors were associated with the risk categories they were placed in, participants of the "other" stakeholder did not always make the connection; this discrepancy between groups may be due to prior exposure to similar concepts in the fields of research and planning. Participants were mostly able to identify the main objectives of the map, radar chart (referred to as the wind-rose plot in the evaluation), and bar

plots of risk factors, covid- case and death count; however, on average researchers were not able to fully use the radar chart for its intended purpose.

Table 13: Consistency and standards- Counties Dashboard Evaluation Results

Survey Question	Research (n=14)	Planning (n=5)	Other (n=5)	All (n=24)
Risk category colors were consistent amongst the different modules (wind rose, covid plots, risk factors bar plot, and map)	4.1	4.6	4.4	4.3
It was easy to identify what risk category I was looking at based on the color gradient of the risk factors.	3.7	4.4	4.4	4.0
The county drop down was easy to find and use.	3.8*	4.6	3.8	4.0*
Average	**3.9**	**4.5**	**4.2**	**4.1**

Consistency and standards questions had an overall average score of 4.1. All participants found that the colors used throughout the dashboard between components were consistent, but, researchers did not always associate color to risk categories and thus, did not find it easy to identify which risk categories were chosen based on the color scheme of the risk factor plots and map. Both researchers and the "other" healthcare group, on average, were not able to easily identify where the county-drop down menu was located.

Table 14: Recognition rather than recall – Counties Dashboard Evaluation Results

Survey Question	Research (n=14)	Planning (n=5)	Other (n=5)	All (n=24)
There were helpful prompts on how to use the features of the "Counties" dashboard.	3.4	4.4	3.4	3.6
I was able to find the county I was interested in.	4.2	4.6	4.0	4.3
I was able to select risk factors for viewing on the map.	4.2	4.6	4.6	4.4
I could easily find information about the selected county from each component (map, bar plot, wind rose plot, covid plots)	4.1	4.6	4.6	4.3
Average	**4.0**	**4.6**	**4.1**	**4.1**

Recognition rather than recall evaluation questions scored an average score of 4.1. All evaluators were able to find the counties they were interested in, choose and visualize different risk factors on the map, and had an easy time finding information about each county from the various components. Researchers and the "other" healthcare evaluators found that the instructions did not provide as much value when it came to understanding how to use the dashboard.

Table 15: Flexibility and efficiency of use – Counties Dashboard Evaluation Results

Survey Question	Research (n=14)	Planning (n=5)	Other (n=5)	All (n=24)
I could select a county using the drop-down menu or the map.	4.1	4.6	4.4	4.3
Average	**4.1**	**4.6**	**4.4**	**4.3**

The **flexibility and efficiency of use** survey question measured whether evaluators could use the drop-down menu or the map to select a county. Overall, this question had an average score of 4.3. Based on previous questions about finding and using the county-drop down menu, researchers and the "other" stakeholder group found it easier to select counties from the map.

Table 16:Aesthetic and minimalistic design – Counties Dashboard Evaluation Results

Survey Question	Research (n=14)	Planning (n=5)	Other (n=5)	All (n=24)
All components of the dashboard were related to covid-19 and/or covid-19 risk factors.	3.9	4.2	4.2	4.0
The layout of the dashboard components highlighted the important features of the dashboard.	3.7	4.6	3.8*	3.9*
Each dashboard element was labeled appropriately (Risk factors, Wind Rose Plots, Covid Plots, Map visualization)	4.2	4.6	3.6	4.2
Average	**3.9**	**4.5**	**3.9**	**4.0**

The **aesthetic and minimalistic design** questions had an overall average score of 4.0. Researchers and those in "other" healthcare group found that the layout of the dashboard was not ideal for highlighting the important features of the dashboard. There were some in the "other" group that did not think each element was appropriately labeled. Researchers also had lower scores when it came to the relationship between COVID-19 and some of the components of the dashboard.

5.4.2. Behavior Change

Table 17: Behavior Change - Counties Dashboard Evaluation Results

Survey Question	Research (n=14)	Planning (n=5)	Other (n=5)	All (n=24)
The counties dashboard has provided me with insight into different risk factors that I did not consider before.	3.9	4.4	4.6	4.2
I can see myself referencing the counties dashboard again to aid with my projects/field of work	3.4	4.4	4.0	3.7
Average	**3.6**	**4.4**	**4.3**	**3.9**

Behavior change questions scored an average of 3.9. Participants from the planning and "other" stake holder group reported that they learned about new risk factors and would reference the dashboard again. Unfortunately, this was not always the case for researchers who had a lower average score when it came to referencing the dashboards again to aid with projects or their field of work.

5.4.3. System Implementation

Table 18: System implementation - Counties Dashboard Evaluation Results

Survey Question	Research (n=14)	Planning (n=5)	Other (n=5)	All (n=24)
I found that the counties dashboard was easy to use.	3.4	4.4	3.8	3.7
I found that health assessment was easy to understand.	3.4*	4.6	4.2	3.8*
The risk assessment and risk factors data can be used when considering different scenarios for pandemic mitigation for different counties.	3.8	4.6	4.8	4.2
The risk assessment and risk factors data can be referenced when conducting research for different counties.	3.9	4.6	4.6	4.2
The risk assessment and risk factors can aid with public health decisions at the county level.	3.8	4.6	4.6	4.1
I found the risk factor data to be reliable and up to date.	3.4	4.6	4.2	3.8
I found the counties dashboard "how to use" guides useful.	3.1	4.4	4.0	3.5
I found that the choice of data representation was appropriate.	4.0	4.6	4.6	4.3
Average	**3.6**	**4.6**	**4.4**	**3.9**

Evaluators from the planning and "other" stakeholder groups found that the **system implementation** of the dashboard was successful, having an average score of 4.6 and 4.4 respectively. The researcher average score was much lower at 3.6, resulting in an overall average score of 3.9. Researchers were more skeptical when it came to the validity of data; this most likely was a side effect of evaluators not having access to data source information during this evaluation. Researchers also did not find the "how to use" guide useful which sets up the foundational knowledge of how to use the counties dashboard contributing the ease of use. A majority of participants found that the dashboard could be referred to when planning

pandemic mitigation, making public health decisions and conducting research which fulfills the main objective of the *Counties* dashboard and that the data representation was sufficient.

5.5. Counties Dashboard Evaluation Discussion

Table 19: Counties Dashboard Survey Results

Perceived Engagement						Behavior Change	System Implementation
Visibility of System	Match between the system and the real	Consistency and standards	Recognition rather than recall	Flexibility and efficiency of use	Aesthetic and minimalistic design		
4.3	3.8	4.1	4.1	4.3	4.0	3.9	3.9
4.1							

Overall, the *Counties* dashboard had an average score of 4.1 in the perceived engagement evaluation, 3.9 in the behavior change evaluation, and 3.9 in the system implementation evaluation. Evaluators were able to explore the different components of the *Counties* dashboard for a county of interest while learning about different risk factors. The main issues of the *Counties* dashboard are found in evaluation categories: match between system and the real world, behavior change, and system implementation. Amongst all three groups, the risk assessment was not fully grasped. The "how-to-use" guides did not thoroughly explain how each score was derived, and the equations found in the risk assessment module were not adequate. To provide more information, an in-depth explanation of how each score is derived (and an example) can be added to the "how-to-use" tab. Visualizing the distribution of a risk factor through the use of a histogram plot with a point indicating where a selected county falls within the population can increase user understanding of how a factor's risk value was determined. Along with better risk assessment explanations, a detailed "how-to-use" guide

with gifs or a video with commentary can be created that steps users through the main functionality and components of the dashboard. Helpful prompts can also be added to the dashboard for noted problem areas such as: where the county-drop down is located and how it can be used, descriptions of each risk category, more references to the category color schemes, and additional indicators of selected risk factors and how to select a risk factor for visualization (this specifically fell short during the task analysis).

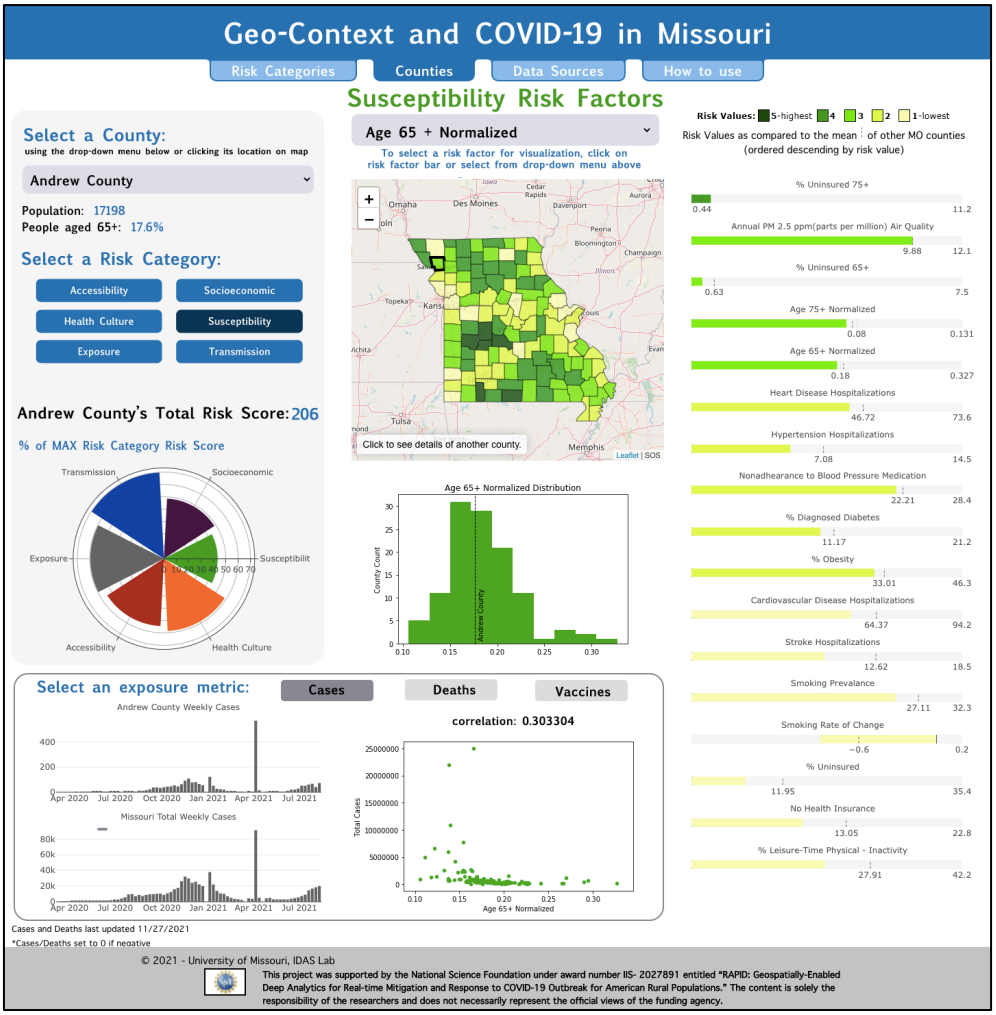


Figure 20: Categories dashboard re-design mock-up

To improve engagement and relevance for researchers, more exploratory elements can be added to the dashboard such as histograms for the risk factors (as mentioned before) and

correlation analysis between exposure metrics (deaths, cases, vaccine rates) and the risk factors through the use of scatter plots or heatmaps. A mock-up of a potential re-design can be seen in **Figure 20**. Additional features not seen in the mock-up are hover events. When a user hovers over a risk category, a detailed description can be added to give users extra context about what risk factors might be found in each category; this idea can be added to different components on the dashboard such as the total risk score.

5.6. Risk Categories Dashboard – Task Results

All task data preparation mentioned in section 5.3, was followed; users who did not attempt a task (click activity count = 0) were removed from the analysis. There were a few participants that skipped the last task of this evaluation.

Table 20: Risk Categories dashboard, RCT01 Results

Risk Categories Dashboard: Task Evaluation 1 (RCT01) Generate risk assessment that includes Susceptibility, Transmission, and Socioeconomic risk categories and highlight county of choice.			
Volunteer type	**First Click Analysis**	**Average/Median Time for successful completion**	**Success rate**
Research n=11	100%	1 min 34 sec/ 43 sec	73%
Planning n=4	75%	17 sec/17 sec	25%
Other n=4	100%	16 sec/17 sec	100%
All n=19	95%	1 min 4 sec/ 18 sec	68%

During the *Risk Categories* dashboard: task evaluation 1 (RCT01), participants were asked to generate a risk assessment that includes the risk categories: susceptibility, transmission, and socioeconomic and then highlight a county of choice. There are a few paths of minimum clicks that users can take that follow the general sequence: click on susceptibility, transmission, and

socioeconomic buttons for selection, the accessibility button to de-select, and then click on the drop-down menu found in the highlight module and select a county (5 clicks). Evaluators likely assumed that the highlight functionality would be similar to that found on the *Counties* dashboard and disregarded the "highlight county" module. To prevent this confusion, the question should have been more specific. As this error was made by all participants, evaluators were only tested on their ability to aggregate the risk factors. This task had a success rate of 68% with an average success duration of 1 min 4 seconds and a median duration of 18 seconds. The first click was deemed successful if an evaluator selected one of the following risk buttons: accessibility, transmission, susceptibility, or socioeconomic. If an evaluator clicked on the map with the intention of highlighting the county, this was accepted due to the inconsistency between dashboards and misleading task descriptions. The first click success rate of RCT01 was 95%. The evaluator who failed this test clicked on the rural urban continuum slider first, which was not related to the prompt and failed the task. 6 evaluators did not complete RCT01 correctly; 2/6 evaluators explored the rural urban slider and selected the wrong risk factors, 3/6 selected the wrong risk factors, and 1 only clicked on the map. Although there were evaluators who did not successful complete this task, most were exposed to the category aggregation functionality.

Risk Categories dashboard: task evaluation 2 (RCT02) asked evaluators to create a risk assessment including all risk categories and then apply the rural urban continuum filter with range 1-3. There are two ways that this task can be completed; one path involves fewer clicks.

Table 21: Risk Categories dashboard, RCT02 Results

Risk Categories Dashboard: Task Evaluation 2 (RCT02) Generate risk assessment for all risk categories only include counties that fall in Rural Urban Continuum spectrum between 1 and 3.			
Volunteer type	**First Click Success Rate**	**Average/Median Time for successful completion**	**Success rate**
Research n=11	91%	20 sec/ 23 sec 13 sec/ 6 sec*	36% /45%*
Planning n=2	100%	N/A 6 sec /6 sec*	0%/ 50%*
Other n=3	100%	49 sec/49 sec 19 sec/19sec*	67%/ 100*
All n=16	94%	30 sec/ 27 sec 14 sec/ 9 sec*	38% / 56%*

Users can click on the "select all" button and then slide the right side of the slider to 3 (2 clicks, 6 events that occur from the slider) or users can click on accessibility, exposure, and health culture risk buttons (if they successfully completed RCT01) and then slide the right side of the slider to 3 (4 clicks, 6 events that occur from the slider). 94% of evaluator first clicks was on one of the risk categories buttons or the slider as described above. After successfully clicking on a button in the appropriate direction, many users failed this task due to not selecting all the risk categories. Because the rural urban continuum filter is a very important feature of this dashboard, success rates and duration of using the slider only were also reported in **Table 21** and marked with an asterisk (*). 38% of participants successfully completed the full task and 56% of participants successfully set the rural urban continuum filter in range 1-3 with an average/median success duration of 30 sec/ 27 sec (14 sec/ 9 sec – just filter). 10 evaluators did not successfully complete RCT02; 3/10 set the correct filtered range but did not select all risk categories (as accounted for above with additional reported values), 6/10 did not set the right filter range, and one of the evaluators did not set the filter.

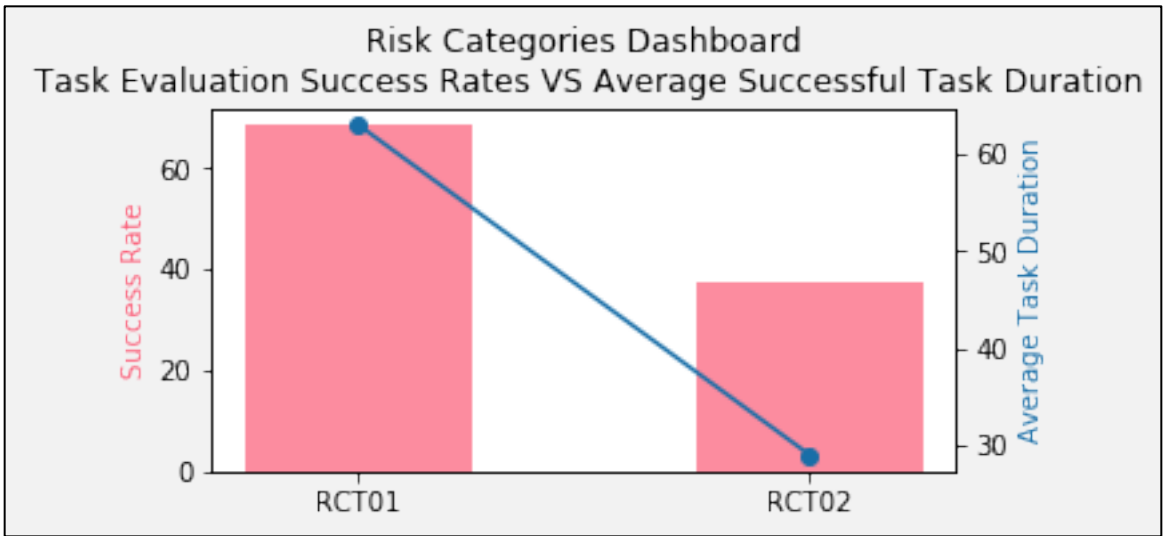


Figure 21: Risk Categories Dashboard Task Evaluation Summary

Unlike the *Counties* dashboard evaluation, the tasks in the Risk Categories evaluation were not created to grow in difficulty; the success rates reported imply otherwise, but fewer participants attempted RCT02 which may have skewed the data slightly. What is interesting is that most users were able to aggregate different combination of risk factors and use the rural urban continuum filter but did not set the risk assessment up to match the requirements from the task description, resulting in lower success rates. RCT01 took evaluators on average ~30 seconds longer than RCT02; as with CT01, it is possible that because RCT01 was a participant's first time using the dashboard, they may have taken additional time to become familiar with the different components of the dashboard prior to selecting the risk categories for the assessment. Those that successfully completed RCT01 were familiar with risk category aggregation and more often used the select all button followed by sliding the slider to 3. Having a "select" all button and being more familiar with the dashboard may have contributed to the lower duration of the second task.

5.7. Risk Categories Dashboard – Survey Results

Like with the *Counties* dashboard survey, results are reported per stakeholder group. No questions were left unanswered.

5.7.1. Perceived Engagement

Table 22: Visibility of system - Risk Categories Dashboard Evaluation Results

Survey Question	Research (n=13)	Planning (n=5)	Other (n=5)	All (n=23)
It was clear which risk categories were selected and included in the risk assessment.	4.1	4.6	4.8	4.3
I was able to identify what the rural urban continuum filter setting was.	3.7	4.6	4.4	4.0
I could identify which county was selected/highlighted.	4.4	4.4	4.8	4.3
Average	**4.1**	**4.5**	**4.7**	**4.3**

The **visibility of system** evaluation questions had an average score of 4.3. Participants were able to distinguish which risk categories were selected and included in the risk assessment and to identify which county was selected/highlighted. Planning and the "other" healthcare evaluators were able to identify the way in which the rural urban continuum filter was set; there were researchers who ranked this question lower.

Table 23: Match between the system and the real world - Risk Categories Evaluation Results

Survey Question	Research (n=13)	Planning (n=5)	Other (n=5)	All (n=23)
I could find relationships between risk categories and how rural/urban a county is.	3.6	4.6	4.8	4.1
It was clear to me what type of risk each risk category was referring to.	3.7	4.6	4.8	4.2
I could determine which counties have the highest/lowest risk.	3.9	4.4	4.8	4.1
Average	**3.7**	**4.5**	**4.8**	**4.1**

The **match between the system and the real-world** evaluation questions scored 4.1 on average. Planners and the "other" healthcare participants reported that they could find relationships between risk and how rural or urban a county is, had a good understanding of what the risk categories covered, and were able to determine which counties had higher/lower risks. This was not consistent with researchers, but expected based on their responses from the *Counties* dashboard survey evaluation. Researchers reported that they did not fully understand how the risk assessment was derived which could have impacted their experience and interpretation of the *Risk Categories* dashboard as it is a high-level view of the risk assessment.

Table 24: Consistency and standards - Risk Categories Evaluation Results

Survey Question	Research (n=13)	Planning (n=5)	Other (n=5)	All (n=23)
The highlight county drop-down was easy to spot and use.	3.5	4.6	3.8	3.8
It was clear that the range sliders filtered the counties on the map.	4.2	4.6	4.6	4.3
All elements were labeled according to their functionality or the data they displayed.	3.8	4.6	4.8	4.2
Functionality was consistent between the "counties" dashboard and the "risk categories" dashboard.	3.8	4.6	4.2	4.1
Design was consistent between the "counties" dashboard and the "risk categories" dashboard (buttons, map, general element functionality).	4.0	4.6	4.4	4.2
Average	**3.9**	**4.6**	**4.4**	**4.1**

Consistency and standards questions had an average score of 4.1. Most evaluators reported that the design was consistent between the *Counties* and *Risk Categories* dashboards and that it was clear to them that the rural urban continuum sliders were used for filtering the map. Researchers did not always find the functionality of the dashboards to be consistent, which may have been influenced by the difference of the map click functionality. On the *Counties*

dashboard when the map is clicked a county is highlighted and data is filtered to that county. On the *Risk Categories* dashboard when the map is clicked users are directed to the *Counties* dashboard to begin the "deep dive" into different risk factors. During the evaluation, this functionality was shut off so that users would stay on the *Risk Categories* page. Users were not able to find the county drop-down menu easily (as seen in the reported scores and during the task analysis) and assumed that clicking on the map would be consistent with the functionality they were previously exposed to.

Table 25: Recognition rather than recall - Risk Categories Evaluation Results

Survey Question	Research (n=13)	Planning (n=5)	Other (n=5)	All (n=23)
There were helpful prompts on how to use the features of the "Risk Categories" dashboard.	3.2	4.6	4.4	3.8
I was able to highlight a county on the map that I was interested in.	3.9	4.4	3.6	4.0
I was able to filter between rural and urban counties.	4.0	4.6	4.6	4.3
I was able to generate a customized risk assessment based on specific risk categories.	3.5	4.4	4.6	4.0
Average	**3.7**	**4.5**	**4.3**	**4.0**

Recognition rather than recall had an average score of 4.0. Planning and the "other" healthcare evaluators found that the prompts of the dashboard were helpful and that they were able to generate risk assessments based on specific risk categories while applying a rural or urban filter. The highlight module was not easily located as mentioned before, so participants were not always able to easily highlight/locate a county they were interested in. Researchers did not feel as though the prompts were as helpful and also had issues with the generation of customized risk assessments.

Table 26: Flexibility and efficiency of use - Risk Categories Evaluation Results

Survey Question	Research (n=13)	Planning (n=5)	Other (n=5)	All (n=23)
I could easily select all risk categories or reset the risk assessment to the default risk category setting.	3.5	4.6	4.8	4.1
I could select different combinations of risk to visualize throughout Missouri counties.	3.9	4.6	4.8	4.2
Average	**3.7**	**4.6**	**4.8**	**4.2**

Flexibility and efficiency evaluation questions had an average score of 4.2, where planning and the "other" healthcare evaluators had an average score of 4.6 and 4.8 respectively and researchers had a lower average score of 3.7. Researchers did not find that the aggregation/de-selecting of all risk categories to be an easy task; this may be due to the "reset" and "select all" buttons having a different design than the risk category buttons. Risk category buttons are rounded, blue rectangles on the *Counties* dashboard. To remain consistent, this design is also used on both the *Risk Categories* and *data sources* webpages. The "select all" and "reset" functions are not risk categories, so they were not placed in a blue button. However, not having a container may have misled some users to believe they were not clickable buttons.

Table 27: Aesthetic and minimalistic design - Risk Categories Evaluation Results

Survey Question	Research (n=13)	Planning (n=5)	Other (n=5)	All (n=23)
All components of the dashboard were related to determining the type and magnitude of risk throughout the counties of Missouri.	4.0	4.6	4.6	4.3
Average	**4.0**	**4.6**	**4.6**	**4.3**

A majority of participants found that the *Risk Categories* dashboard could be used to learn about the magnitude of different types of risk throughout the counties of Missouri, therefore

having an overall average score of 4.3 in the **Aesthetic and minimalistic design** evaluation category.

5.7.2. Behavior Change

Table 28: Behavior Change - Risk Categories Evaluation Results

Survey Question	Research (n=13)	Planning (n=5)	Other (n=5)	All (n=23)
The risk categories dashboard has provided me with insight about the different types of risk throughout the rural and urban counties of Missouri.	3.7	4.6	4.8	4.1
I can see myself referencing the risk categories dashboard again to aid with my projects/field of work	3.4	4.6	4.2	3.8
Average	**3.5**	**4.6**	**4.5**	**4.0**

The **Behavior Change** evaluation had an average score of 4.0. Planning and "other" healthcare evaluators thought that the dashboard provided them with more context regarding different types of risk throughout the rural and urban counites of Missouri and that they would reference the *Risk Categories* dashboard again. The researcher group had an average score of 3.5.

5.7.3. System Implementation

The **system implementation evaluation** had an average score of 3.9 where planning and "other" healthcare evaluators had an average score of 4.6 and 4.5 respectively, and research evaluators had an average score of 3.4. A majority of participants found that the dashboard could be used to learn about risk throughout rural and urban counties of Missouri to help with public health decisions and research. Researchers found that the "how-to-use" guide for this dashboard was not helpful which likely impacted their experience using this dashboard resulting in a lower score for the ease of use (3.0) and being able to generate customized risk

assessments (3.4). Not having a solid understanding of how to use dashboard may also explain why researchers scored lower in the behavior change section above.

Table 29: System Implementation - Risk Categories Evaluation Results

Survey Question	Research (n=13)	Planning (n=5)	Other (n=5)	All (n=23)
I found that the risk categories dashboard was easy to use.	3.0	4.6	4.4	3.7
I found it easy to generate customized risk assessments.	3.4	4.4	4.4	3.9
Learning about risk throughout the urban and rural counties of Missouri can help with public health decisions and/or research.	4.0	4.6	4.6	4.3
I found the risk categories "how to use" guide useful.	2.9	4.4	4.4	3.7
I found that the choice of data representation was appropriate.	3.9	4.8	4.4	4.2
Average	**3.4**	**4.6**	**4.5**	**3.9**

5.8. Risk Categories Dashboard Evaluation Discussion

Table 30: Risk Categories Dashboard Survey Results

Perceived Engagement						Behavior Change	System Implementation
Visibility of System	Match between the system and the real	Consistency and standards	Recognition rather than recall	Flexibility and efficiency of use	Aesthetic and minimalistic design		
4.3	4.1	4.1	4.0	4.2	4.3	4.0	3.9
4.1							

Overall, the *Risk Categories* dashboard had an average score of 4.1 in the perceived engagement evaluation, 4.0 in the behavior change evaluation, and a 3.9 in system implementation. A majority of participants were able create customized risk assessments based on selected risk categories and apply a rural urban continuum filter to learn about the

relationships between risk and rurality. Users were not always able to quickly locate where a county of interest was located due to the county "highlight" module not being easily found as seen in the task analysis and through responses in the survey. The county drop-down highlight module is currently located in the bottom-left corner of the dashboard. To make this feature more visible, the drop-down menu can be placed in a more central location with labels that describe its intended functionality.

While planning and "other" healthcare evaluators found that this dashboard was easier to use compared to the *Counties* dashboard and would use it again in their field of work, elements of the dashboard fell short for researchers. Researchers did not find the "how-to-use" guide helpful and previously reported (during the *Counties* dashboard) that the derivation of the risk assessment was not clear which may have impacted their overall experience using the *Risk Categories* dashboard which is a high-level view of the risk assessment. More detailed "how-to-use" guides can be created to provide users with more direction on how to navigate the dashboard through the use of gifs or a video with commentary (as suggested with the *Counties* dashboard). Detailed descriptions of each component can also be added to help guide a user's exploration. To add more dimension to the dashboard, a risk assessment breakdown component can be implemented (depending on which county is selected) that displays the ratio of risk categories (similar to the radar chart on the *Counties* dashboard). Scatter plots can be added for further exploration of relationships between customized risk assessment and exposure metrics tying COVID-19 to this dashboard. A potential re-design mock-up can be seen in **Figure 22** below.

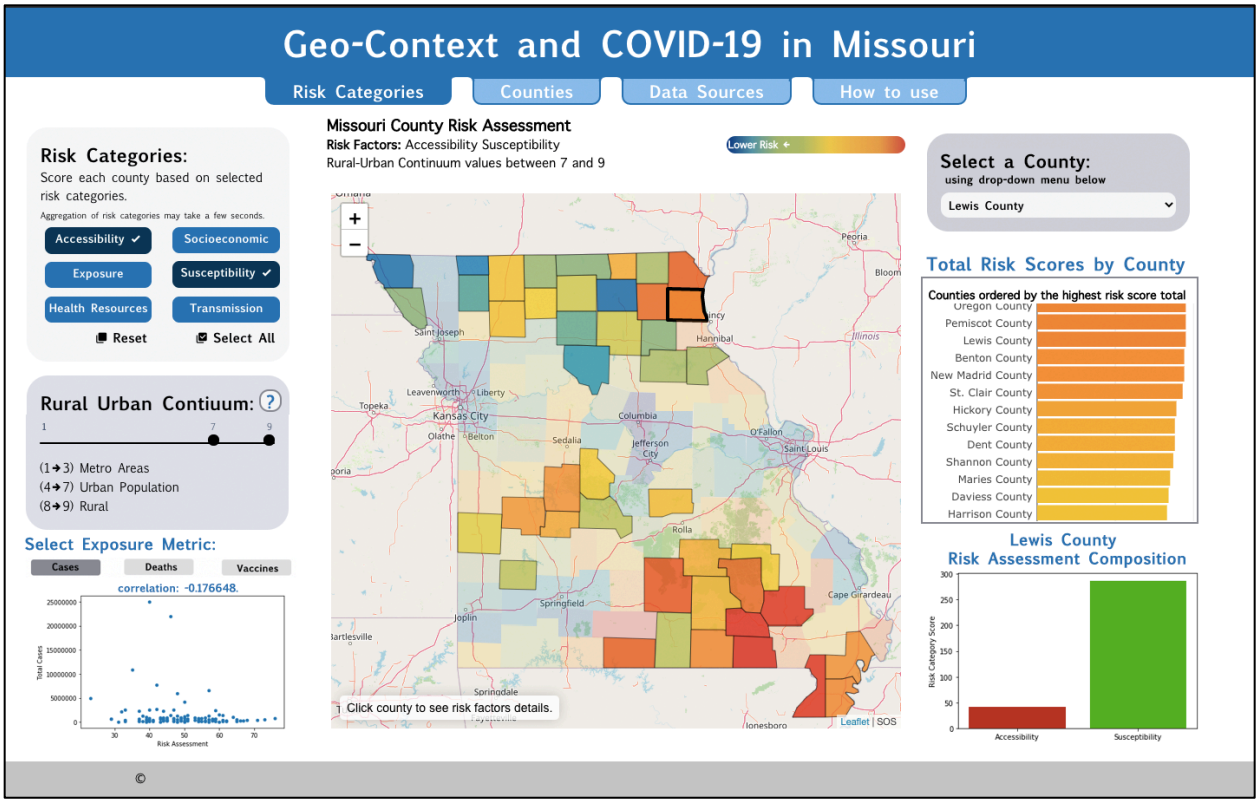


Figure 22: Risk Categories redesign mock-up

6. Conclusions and Future Work

Both dashboards of the "Geo-Context and COVID-19 in Missouri" website were found to be useful for pandemic mitigation, public health decisions, and research despite slight usability issues. With the addition of exploratory elements, a deeper dive into the derivation of the risk assessment, and a more optimized design, policy makers, practitioners and research stakeholders will have the optimal tool for learning about different risk profiles of rural counties in Missouri that might not always be obvious due to urban biased news/data.

Future work consists of a re-design of each dashboard based on the evaluation results found in this thesis and possibly another iteration of evaluations from the stakeholder group that was not fully represented during this thesis work (state/regional/county planning

committees). To ensure that this website remains relevant and the data is up-to-date, more automation can be implemented on the back-end to simplify the addition and removal of data; for example, each risk factor was scored manually. To make this process more efficient with less error, functions can be created to read in risk factor data and to automatically generate risk values, risk category scores, and total risk scores. Additionally, our framework and risk assessment can be applied to all states in the United States where data is available, allowing for additional functionalities such as comparison of similar counties between different states, state wide risk assessments, more data/features for correlation analysis, and possibly a tool for generating statistical models with data. This website would not only be tool for exploratory analysis but a hub of data that can be used in other projects.

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