TRANSIT EQUITY & ENVIRONMENTAL HEALTH IN BALTIMORE CITY

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BLOOMBERG SCHOOL
of PUBLIC HEALTH

BALTIMORE
TRANSIT
EQUITY
COALITION

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EXECUTIVE SUMMARY

Introduction

Public transit provides relatively low-cost access to jobs, food, healthcare and increased physical activity. Public transit also reduces pollution and greenhouse gas emissions by taking cars off the roads. Despite these benefits, public transit in Baltimore often fails to get people to their destinations in a reasonable amount of time. This is especially concerning since low-income people of color represent the majority of transit-users in Baltimore, many of whom during the COVID-19 pandemic were classified as "essential workers".

This project, a collaboration among Johns Hopkins University, the Baltimore Transit Equity Coalition (BTEC), and Baltimore community members, aims to better understand the relationship among the public transit system, air pollution, and health impacts in the Baltimore region. We hope the information can be used to determine which communities might benefit the most from investments in transit.

Methods

We analyzed four themes: transit, social vulnerability, air pollution, and health. Each theme had indicators drawn or derived from the U.S Census Bureau (including American Community Survey (ACS) and LEHD Origin-Destination Employment Statistics data), the Centers for Disease Control and Prevention, the Maryland Transit Administration (including their General Transit Feed Specification data), the EPA's EJ Screen, the University of Maryland's Maryland EJ Screen, and the Maryland Cancer Registry. For each indicator under the four themes, we calculated a percent rank (0-100) relative to other Baltimore geographies, so that a higher rank indicated a community more in need compared to the rest of the city. Each theme's score was the average of all its indicators. The analysis focused on people living and working in Baltimore (about 40% of whom are considered "essential")[1]. Future efforts will include the entire metropolitan area.

Indicators

More details on these indicators can be found in the full report below.

Transit indicators

- Number of transit stops in the census tract
- Distance over a half mile to high frequency transit routes
- % of workforce commuting by public transit
- Estimated average commute time
- Estimated difference in average commute comparing public transit versus car
- % of population commuting by transit with a commute >45min

Social Vulnerability indicators

- Socioeconomic status
- Household Composition & Disability status
- Minority status & language abilities
- Housing type & Transportation access

Air pollution indicators

- Concentration of Particulate Matter less than 2.5 microns
- Ozone concentration
- Concentration of Particulate Matter from diesel exhaust
- Respiratory Hazard Index
- Proximity to Traffic

Health indicators

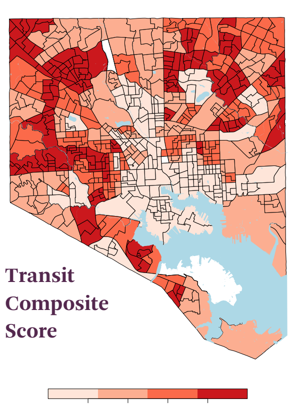
- Asthma
- COPD
- Lung Cancer
- COVID-19
- Heart Disease
- Low Birth Weight

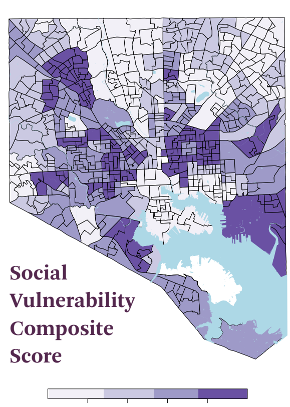
Results and Recommendations

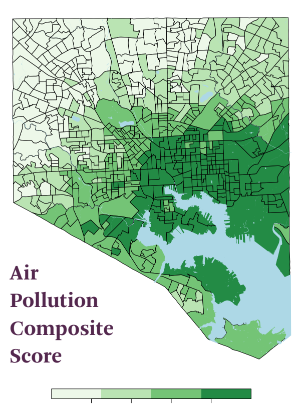
In all the maps, darker color indicates areas of greater need. For the transit score, many indicators appear to increase further away from the city center: average commute time, percent of public transit users with commute >45 minutes, difference in average commute time between public transit and personal vehicle use, and distance to high frequency transit stops. However, some tracts closer to the city center have a disproportionate need for investment based on their overall scores.

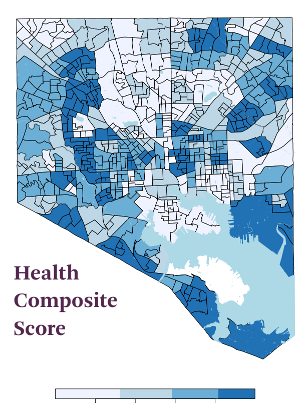
Most of the social vulnerability and health maps reflect the notorious ‘White L’ and ‘Black Butterfly’ associated with Baltimore, with more low-income, minority-populated communities located in the darker areas and wealthier, white-populated communities located in the lighter areas in the middle of the map. The air pollution map reveals decreased air quality in the downtown areas close to highways and the Patapsco River.

In the final composite map, it is clear that neighborhoods in the Black Butterfly with higher social vulnerability have greater need, extending to the southern tip of Baltimore. This calls for greater investment in transit in neighborhoods such as the ones identified in the Composite: Areas in Highest Need map.

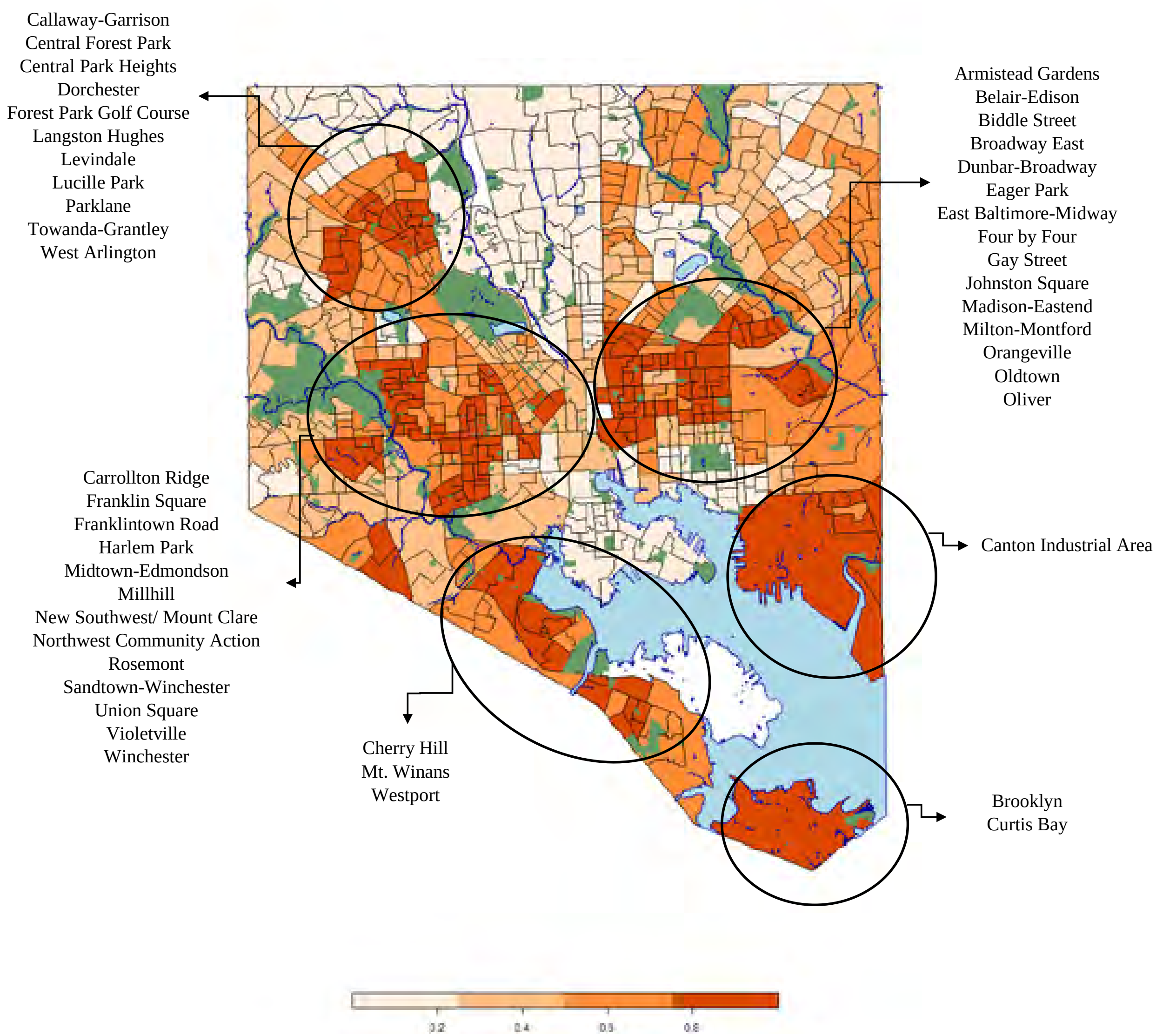








Composite: Areas in Highest Need (by Transit, SVI, Pollution, Health)



INTRODUCTION

Public transit provides access to jobs, food, and healthcare, while also producing far less pollution and greenhouse gas emissions than trips in personal vehicles. People who use public transit also typically get more physical activity each day due to walking or biking to and from transit stops.

Despite these benefits, public transit in Baltimore struggles to get people where they need to go in a reasonable amount of time. The majority of people in Baltimore using transit are low-income and black or brown people. During the COVID-19 pandemic, many transit riders served as “essential workers”.

This project aims to better understand the relationship between the public transit system, key air pollutants linked to transit, and key health impacts related to transit in the Baltimore region. The goal is to make recommendations as to which communities would benefit the most from investments to improve public transit.

In order to accomplish these objectives, Phase I involved the creation of maps to describe transit, social vulnerability, transit-related air pollution, and health outcome indicators in Baltimore City. In Phase II we will expand the analysis to include counties outside Baltimore City. The various maps will be combined to help identify areas with the greatest need for investment and to make recommendations to the City Council, the Maryland legislature, and the Transportation and Climate Initiative.

BACKGROUND

Transit accessibility looks at potential opportunities to reach a destination and ease of travel. Elements may include population density, job availability, or service/facility availability at the destination. Transportation elements include the distance to transit, the frequency of the transit, the cost of travel (including time that it takes), and the comfort of service. Increased transit accessibility can mean increased access to jobs, grocery stores, social support, and other quality of life measures. Communities’ ability to access resources and opportunities not only relates to local infrastructure but is also impacted by factors such as poverty, which can impose drastic hardships on individuals living in those communities.

Transit use can be driven by **perception of safety** - safety while waiting for a bus and safety while riding the bus. Safety is one of the most debated factors impacting transit-dependent users’ travel behavior. With properly established safety metrics, local officials can measure their progress in establishing an equitable transit system. Continuous monitoring of safety performance data in transit can help address safety-related challenges and properly allocate resources.

Through a long history of discriminatory mortgage lending, a practice known as **redlining**, people of color were limited in where they could live in the city.[2] These communities were also the first to be uprooted and bulldozed for highways.[3] This served to concentrate and displace communities of color over generations. Black communities are also more likely to be located near toxic waste sites, dumps, and other health hazards. Studies show that air quality on average is worse in black neighborhoods, and black people experience twice the health risk from air pollution than white people.[4,5] This iterative process to destabilize and devalue black communities continues to this day with unequal investment in infrastructure, including transit.

One example of the disparity in transportation access is the **Red Line**. The Red Line was a proposed Light Rail Transit (LRT) project that would run from Bayview in the east to Woodlawn in the west in Baltimore City and County, connecting neighborhoods to downtown, institutions, amenities, industrial and commercial centers, and the job opportunities that come along with it. This project was cancelled by Governor Hogan in 2015, and the funds reappropriated to repair roads in majority white communities.[6,7] Redirecting funds from a public transportation project that would have served neighborhoods with high percentages of Black and brown residents to road and highway projects serving predominantly white populations exacerbated disparities in access to jobs and other destinations based on race. Such ongoing preferential treatment of wealthy and white communities ensures that poor communities remain isolated and immobile.

Many studies find that the presence of a robust public transportation system increases air quality by providing an alternative to cars. Cars and trucks burn diesel or gasoline, and this releases exhaust which contains many compounds such as Particulate Matter (PM), Volatile Organic Compounds (VOCs), Nitrogen Oxides (NOx), Carbon Monoxide (CO), and Sulfur Dioxide (SO_2).[8] This exhaust contains compounds that can react to form ground-level ozone.[9] Traffic and congestion **pollute the air** by creating more idling in place as well as causing more starts and stops, which release more emissions.[10] Consolidating more riders into fewer vehicles creates more efficient roadways and decreases congestion, while also improving the fuel efficiency per passenger and reducing air pollution.

The connection between air pollution and **respiratory disease** has long been established. Lungs respond to irritation by constricting muscles and creating mucus. This inflammatory reaction underlies both asthma as well as chronic obstructive pulmonary disease (COPD).[11,12] Chemical reactions of air pollutants in the lungs can also cause DNA damage leading to cancer.[13,14] In fact, the International Agency for Research on Cancer classifies diesel exhaust as a carcinogen.[15]

Oxidative stress and systemic inflammation from air pollution also cause problems outside of the lungs, such as **heart disease, stroke, hypertension, and gestational issues.**[16,17,18] Increased and continued exposure to traffic escalates the probability of adverse effects. As different types of air pollutants (exhaust, particulate matter, and ozone) very frequently occur together, health effects are often studied as a result of the composite and not stratified by pollutants.

Air pollution and related respiratory diseases can also make people more susceptible to illnesses such as the novel 2019 coronavirus. Studies show that African Americans are three times more likely than white Americans to get **COVID-19**, and twice as likely to die from it.[19] Factors thought to contribute to this disparity include pre-existing health conditions, less access to health insurance, essential-worker jobs, multi-generational homes, and population density. As the NEJM puts it, structural racism shapes the distribution of social determinants of health as well as social risk factors.[20] The same residents that develop asthma, COPD, and lung cancer from traffic pollution are also more vulnerable to COVID-19.

The compounds released in vehicle exhaust are not only detrimental to human health but also directly contribute to **climate change**, which in turn impacts health. The Intergovernmental Panel on Climate Change emphasizes that greenhouse gases must be reduced by 50-85% from current consumption to limit global warming to four degrees Fahrenheit.[21] When compared to the average SUV or sedan, buses produce approximately 33% less pounds of carbon dioxide per passenger mile, while the metro, LightRail, and MARC trains can see as much as a 76% reduction in carbon dioxide per passenger mile.[22] Communities with strong public transportation systems can reduce the nation's carbon emissions by 37 million metric tons yearly.[23]

Climate change is not a single threat, but a threat multiplier. Climate instability can present as increased extreme weather events (heat waves, floods, wildfires), sea-level rise, poorer air quality, increased infectious diseases, and disruptions to food and water systems. Vulnerable people and communities who may already struggle with food and energy insecurity, poverty, lack of infrastructure, and mobility limitations are the most likely to suffer the greatest impacts of these changes.[24]

METHODS

For the analysis we started off with five themes: Transit, Social Vulnerability, Safety, Air Quality, and Health. Each theme had various indicators based on readily-available data. For each indicator, we calculated a percent rank, such that a higher rank value indicated an area more in need compared to the rest of the city. Each theme's score was simply the average of all its indicators.

Our analysis focused on Baltimore City. The unit of analysis was typically census *block group* then, if that was unavailable, census *tract*. Census *blocks* are the smallest unit of analysis for the US Census. Census *block groups* represent contiguous census blocks, with an average population of 1,000, and are approximately equal in area[25]. Census *tracts* generally have a population between 1,200 and 8,000, with an optimum size of 4,000 people. A census tract usually covers a contiguous area; however, the spatial size of census tracts varies depending on the population density.[26] Baltimore City is made up of 200 census tracts and 653 census block groups. Maps in the results section display census block group boundaries even when census tract information was necessary due to lack of finer resolution data.

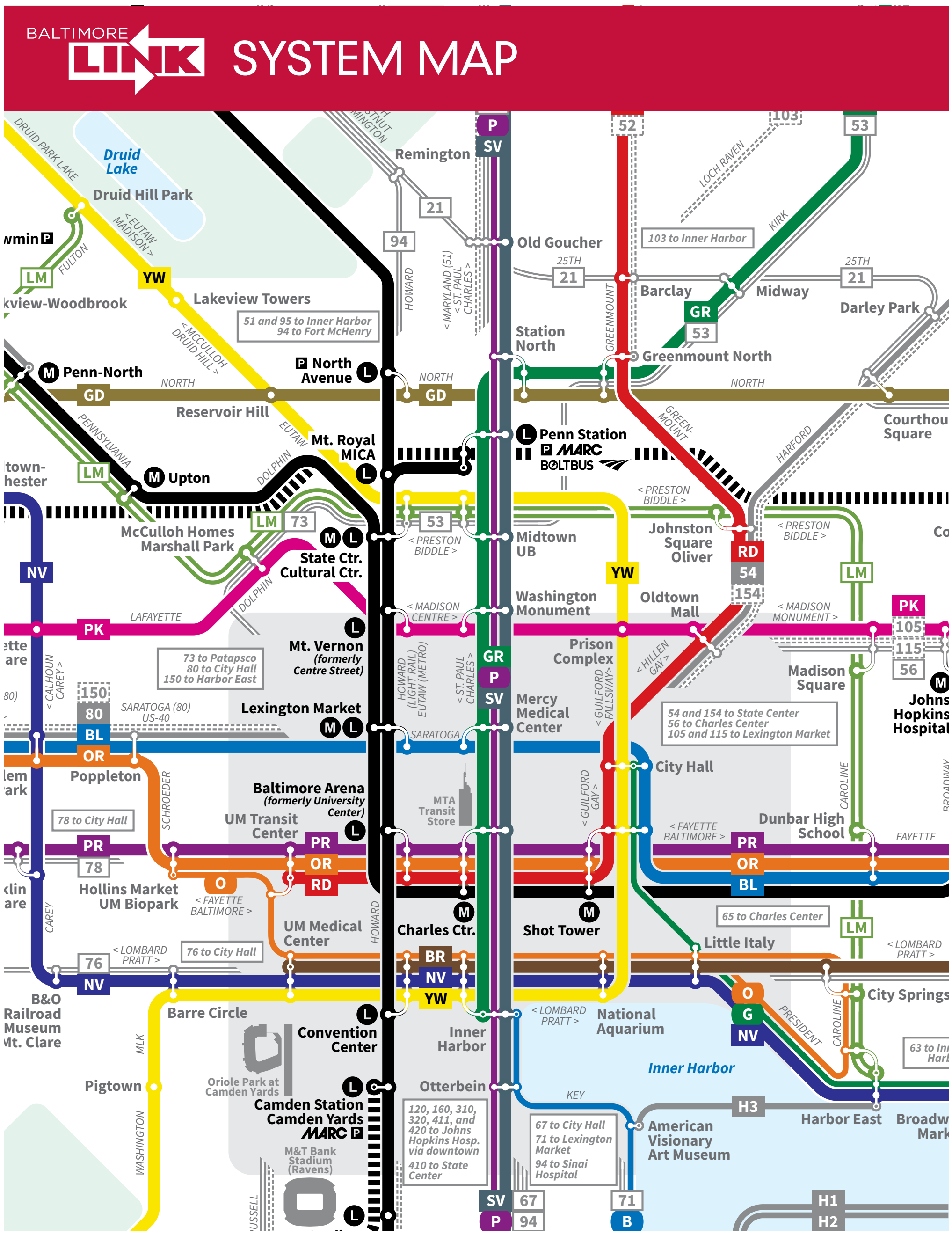
Transit Analysis

The existing BaltimoreLink traverses the city and surrounding suburbs. The spatial coverage of the BaltimoreLink service is illustrated in Figure 1. For simplicity, in this study it is assumed that all trips originate from the centroids of census blocks and end in a centroid of another census block.

The Advisory Board determined which indicators were the most useful and relevant to measure. The transit score was broken into Access and System Performance, which were further broken into various indicators listed below. The research team used various resources, including current maps of the MTA transit system, Census (aka American Community Survey or ACS) data, and General Transit Feed Specification (GTFS) data.

This last resource (GTFS) was developed in 2005 by Google and TriMet for transit agencies to share their schedules, trips, routes, and stops data in an open-source platform that can be used for Google Transit Web-based trip planner. A GTFS dataset consists of several plain text files which have been formatted as Comma-Separated Values (CSV). The team used Google spreadsheets and Geographic Information System tools to collect data and analyze data. Specifically, ArcGIS Pro 2.6.3 and R Studio 3.6.1 were used for geoprocessing of spatial data and statistical analysis.

Figure 1. Baltimore Link Map



Access

Measures of access to transit, when taken together, are meant to describe the ease with which a person can and does use transit. The measures included:

Number of stops in the census tract

The resulting value was reversed in percentile, so that higher numbers indicated a need for greater investment.

Distance over a half mile to high frequency transit routes

A score of "0" meant that the census block centroid was within 0.25 miles of a high frequency transit route (as defined by Maryland Transit Authority). Thus, a higher score meant that a census block centroid was farther from a pick up location on a high frequency transit route.

Percent of the workforce commuting by public transit

Data from the ACS was used to determine what percent of the workforce in each tract used public transit. A higher percentage of the workforce commuting by public transit in a given Census tract indicates that the estimated travel time data in that tract is more reliable.

System Performance

The performance of any transit system can be evaluated by service quality and operating costs. For this report we focused on indicators of service quality.

GTFS data was collected from MTA open source locations and displayed with ArcGIS by using the BetterBusBuffers toolbox, developed by Melinda Morang at ESRI (2015). The toolbox consists of routines for extracting service frequencies from transit data stored in the GTFS format and is used for travel time estimation. The functionality available in this toolbox applies SQL databases and stored query procedures intended to summarize incoming GTFS datasets. BetterBusBuffers toolbox (ESRI) is used to develop the SQL database storing a service frequency value for each MTA bus stop location in Baltimore. Centroids of each census tract are considered as both the origin and destination points.

To travel from census tract A to census tract B using transit services, it is assumed that the walking speed of a person to reach the bus stop is 3 miles per hour and it will take 30 seconds to get on and off the bus. Travel times between census blocks have been calculated such that trips can occur in only one direction, meaning traversal is not allowed in the backwards direction. Ultimately, this work generated a travel time matrix (200 x 200) which provides the estimated travel time between any pair of census tracts for a person taking the fastest path using transit vs traveling by automobile. This information was used to create some of the metrics to describe system performance.

The following indicators were used to measure system performance:

Estimated Average Commute Time

For this indicator we calculated the average time for all workers to get to their various job locations in the City. Data sources for this included:

- LODES data[27] from Foursquare = block group real data
- Number of workers in any given block group commuting to any other block group
- ACS (for census tract estimates for percent of population which commutes to work by any public transit)
- Census tract estimates for travel time by public transit versus private vehicle (generated from GTFS and MTA network information as described above)

By including non-transit commute time, average commute time shows people who choose not to use transit, who could use transit. The average commute time for block group A was calculated as:

workers going to B/total # workers [(% commuting by transit*Time from A to B by public transit) +
% not commuting by transit*Time from A to B by vehicle)] +
# workers going to C/total # workers [(% commuting by transit*Time from A to C by public transit) + % not commuting by transit*Time from A to C by vehicle)] +

... and so forth, summing adjusted commute time estimate for all block groups to which workers in block group A commute.

- Inputs:
    - # of workers in each block group going to various other block groups for employment
    - % of workers commuting by public transit by census tract (ACS estimate)

We repeated this process for all block groups, iterating through all real destinations of workers from that block group to those of job location. This assumes:

- Travel times from block group A to B are between the centroids of the census tracts which A and B each fall into.
- ACS estimates for percent of workforce commuting by public transit are homogenous across block groups within each census tract; similarly, those in a block group equally use public transit (PT) regardless of destination.

The limitations of this calculation include:

- This only looks at the distribution of workers who both reside and work within the city.
- GTFS estimates were limited to census tract to census tract commute times (rather than block group to block group) due to memory/processing limitations
- This uses a private vehicle commute estimate for those not commuting by public transit (doesn't account for carpooling, walking, other forms of commuting which are specified in ACS survey).

Estimated difference between average commute by public transit versus by car

This indicator provides insight into people's decisions as they choose their commute. This was calculated similarly to average commute time in terms of set up with LODES data and Connection Matrix (GTFS) estimates, but no longer uses the ACS estimate of percent of workers commuting by public transit. Instead, this value represents the average commute time between anyone using public transit versus anyone using a car, regardless of how many people are doing either of those things. It still factors in how many people are realistically going to certain places (in other words, mean commute was still weighted by worker destinations).

Key assumptions included:

- workers not taking public transit use a private vehicle (when in fact they could bike or walk, for example).
- estimated travel times by public transit and by personal vehicle generated using census tract centroids as the origin and destination points are reasonable estimates for residents and employers within a given census tract (potentially excluding the last mile barrier).

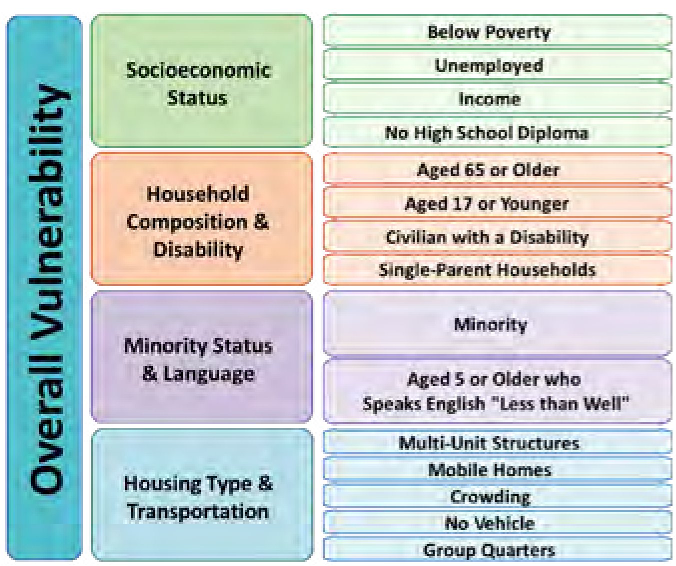
Percent of population commuting by transit whose commute is >45min

The ACS provides commute times by census tract in five-minute intervals between 10 and 60 minutes by type of transportation. Considering only the population who commuted by public transit, we calculated the percent of people whose commute time was more than 45 minutes (summed up the people in intervals above 45 and divided by the total population).

Social Vulnerability Analysis

To better understand the social vulnerability of communities in Baltimore the research team decided to use the Social Vulnerability Index (SVI) developed by the U.S. Centers for Disease Control and Prevention.

SVI indicates the relative vulnerability of every U.S. Census tract based on 15 factors, including unemployment, minority status, and disability. Each tract received a ranking for each variable and for each of the four themes (Socioeconomic, Household Composition & Disability, Minority Status & Language, Housing Type & Transportation), as well as an overall ranking.[28] For our purposes, we used the overall score and recalculated percentiles relative to Baltimore City.



Safety Analysis

We were able to find data on accidents between automobiles and pedestrians, as well as data on accidents between automobiles and bicycles, and data on overall crime. However, this data did not address safety while using transit, so in the end we decided to exclude this theme from the current analysis. **Hopefully, future iterations of this report will include indicators of safety** (perhaps 911 and 311 calls related to transit). Such data could help make recommendations about lighting, presence of peace officers, or other interventions to improve safety.

Air Quality Analysis

The Maryland EJ Screen, a tool created by University of Maryland, was initially used to select five air quality indicators (see table below).[29] Raw data for this tool came from the EPA's EJ Screen at https://gaftp.epa.gov/EJSCREEN/.[30] Raw values were converted to percent rank, which represents their percentile relative to Baltimore City. These ranks were used to create the composite Air Quality Map.

One note on the reliability of the data is that the number of EPA air quality sensors in Baltimore is limited (there are only three).[31] The distance between sensors creates data that portrays regional differences in air quality, but can obscure what could really be going on at the neighborhood level. **Additional research is needed for more granular local air quality measures.**

The National Air Toxics Assessment (NATA) Respiratory Hazard Index is a composite score that includes other indicators in our analysis, such as PM, ozone, and diesel. Despite this overlap, we decided to include the Index because it also contains indicators that would otherwise not be represented in our analysis (NOx, SOx, CO, and lead).

INDICATOR	DESCRIPTION	MEASUREMENT
PM 2.5	Particulate matter in air with a diameter of 2.5 micrometers or smaller. Creates a hazy appearance in the air. Threat to health because the particles are small enough to settle deep in the lungs.	Annual average, reported as micrograms per cubic meter (μg/m3).
Ozone	A pollutant formed from the reaction of volatile organic compounds (VOC) or NOx gases with oxygen and sunlight. This can damage the lungs through a chemical process.	Summer seasonal average of the maximum daily 8-hour concentration of ozone in air (parts per billion).

NATA Diesel PM	Particulate matter from diesel-fueled processes, including semi-trucks, buses, and industrially-fueled generators.	Levels of diesel particulate matter in the air (µg/m3).
NATA Respiratory Hazard Index	An index for health threat by respiratory air toxics. Includes PM, NOx, SOx, ozone, CO, lead, diesel.	The air toxics respiratory hazard index is the sum of hazard indices for those air toxics with reference concentrations based on respiratory endpoints. Each hazard index is the ratio of exposure concentration in the air to the health-based reference.
Traffic Proximity	Exposure to vehicle traffic.	Count of vehicles (average annual daily traffic) at major roads within 500 meters or close to 500 meters, divided by distance in meters. This was calculated by taking the distance to the nearest part of highway, multiplied by the daily traffic estimate for that part of highway, and takes population into account.

Health Indicators Analysis

Health indicators (see Table below) were chosen based on their relevance to the issue as well as availability of data. The data was compiled through several sources, some of which required special requests, multi-step data extraction processes, and communication with the creators of various tools. See "Source" column for notes on data extraction.

It should also be noted that some of these measures are used as a proxy for disease burden. For example, heart disease is represented by hospital discharges for myocardial infarction. This will not capture how many people in each area have heart disease, as they may not all make it to the hospital, or they may not make it out if they do make it there. Also myocardial infarction is one endpoint of heart disease. Many people with the disease may not have experienced an infarction.

Heart Disease and Low Birth Weight values were only accessible in percentiles compared to the state of Maryland for each census tract. A simulation was run to confirm that the Baltimore census tracts could be extracted in their percentile format, then re-scaled to create percentiles for just the City of Baltimore. Because scores were distributed into quartile bins, these bins did not change from the re-scale and this method was confirmed as valid.

All data was compiled, values were re-scored to 100 scale (if needed), and a composite score for each census tract was created.

INDICATOR	DESCRIPTION	MEASUREMENT	SOURCE
Asthma	A disease which causes intermittent reactions that involve airway narrowing, mucus production, and shortness of breath.	Percent of Adults Aged >18 years with current asthma, 2017	CDC National Environmental Public Health Tracking Network's 500 Cities Project. Provides data download with each search. https://ephtracking.cdc.gov/DataExplorer/
Chronic Obstructive Pulmonary Disease (COPD)	Lung diseases caused by repeated irritation, resulting in wheezing, cough, and impaired gas exchange.	Percent of Adults Aged >18 years with current COPD, 2017	CDC National Environmental Public Health Tracking Network's 500 Cities Project. Provides data download with each search. https://ephtracking.cdc.gov/DataExplorer/
Lung Cancer	Cancer of the lungs	Case counts per census tract 2014-2018	Maryland Department of Health: Maryland Cancer Registry. Obtained via special request.

COVID-19	A contagious disease caused by the respiratory virus SARS-CoV-2	The cumulative number of positive COVID-19 cases among Maryland residents within a single Maryland ZIP code.	Initial numbers obtained from UMD's Maryland EJ Screen. Maryland.gov provides zip-code level data. Per UMD, this data was crosswalked to census tract level using https://www.huduser.gov/portal/datasets/usps_crosswalk.html
Heart Disease	Conditions leading to restricted blood flow through the arteries around the heart, causing ischemia.	Percentile (compared to the state of Maryland) of patients released from the hospital after being admitted for a heart attack or heart attack symptoms.	UMD's Maryland EJ Screen.https://p1.cgis.umd.edu/mdejscreen/ Per the "About" page at https://p1.cgis.umd.edu/mdejscreen/help.html, data can be extracted from the tool's GitHub repository at https://github.com/gisumd/EJScreen
Low Birth Weight	Infant weight at birth below a certain threshold, in this case often due to intrauterine growth restriction related to maternal issues	Percentile (compared to the state of Maryland) of babies born weighing less than 5.5 pounds.	UMD's Maryland EJ Screen.https://p1.cgis.umd.edu/mdejscreen/ Per the "About" page at https://p1.cgis.umd.edu/mdejscreen/help.html, data can be extracted from the tool's GitHub repository at https://github.com/gisumd/EJScreen

RESULTS

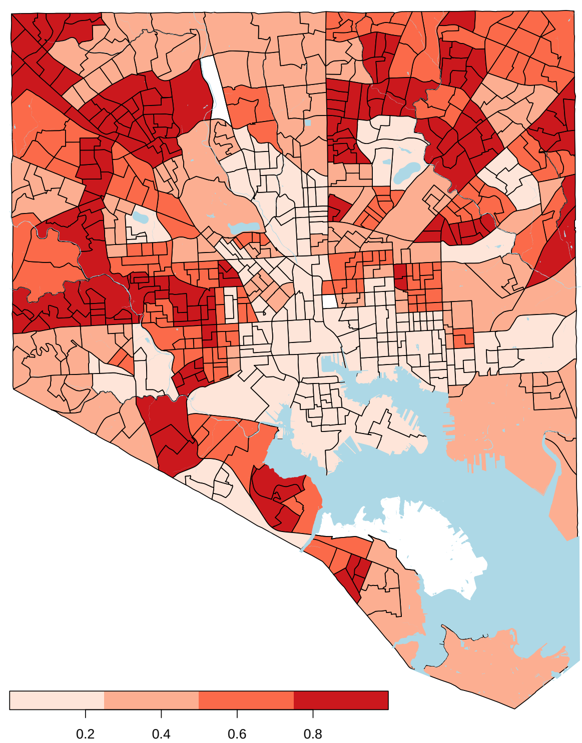
Transit Score

The results were mapped by each indicator. In all the maps, a higher score (darker color) indicates areas of greater need. For example, as mentioned in the Methods section, a higher number of transit stops would be a positive attribute, but for the sake of mapping, the values were reversed so that a higher score indicates fewer transit stops (meaning an area in need of greater investment).

Transit Indicator

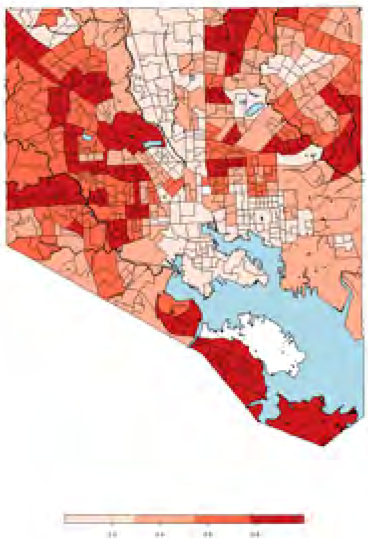
Inputs

- Estimated average commute time
- Percent of population commuting by public transit
- Percent of population commuting by transit whose commute is >45min
- Estimated difference between average commute by public transit versus by car
- Number of transit stops in census tract (*reversed in percentile)
- Distance over a quarter mile to high frequency transit routes

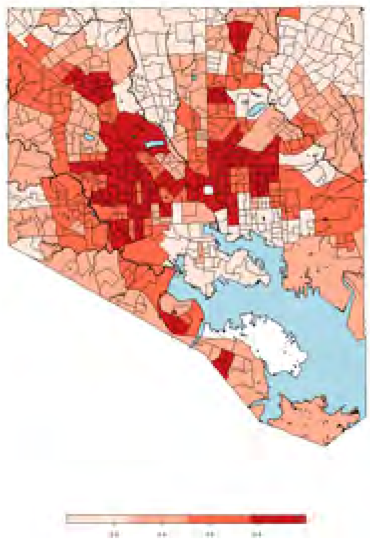


The six maps below illustrate the stratified data for each input:

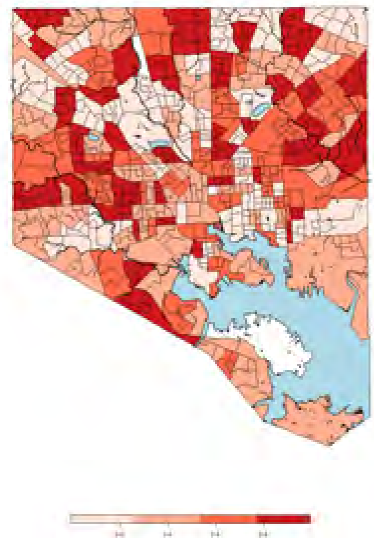
Average Commute Time via Public Transit



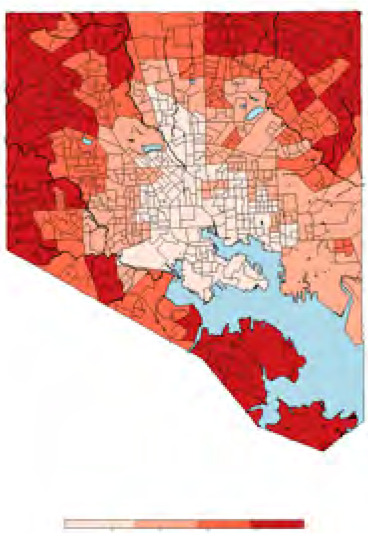
% of Population Commuting by Public Transit



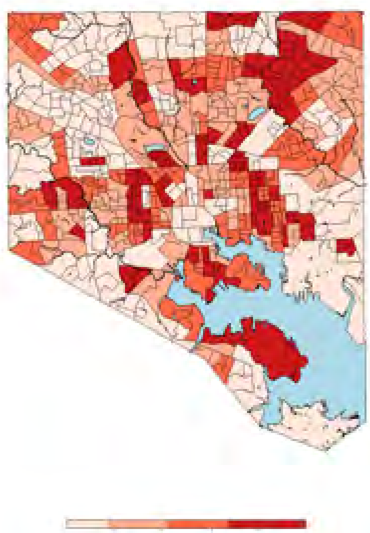
% of Population whose Commute Time >45 min
(out of those taking Public Transit)



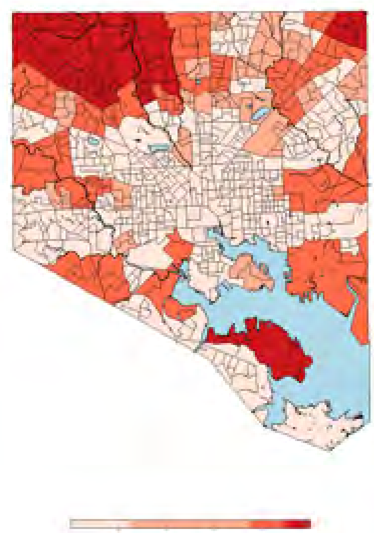
Difference in Average Commute Time



Number of Transit Stops



Distance to High Frequency Transit Stop



All of the following seem to increase further away from the city center:

- Average commute time
- Percent of public transit-utilizing population whose commute is greater than 45 minutes
- Difference in average commute time between public transit and personal vehicle use
- Distance to high frequency transit stops

This is logical, however, there are noticeably some tracts in the city center who do not reasonably align with average commute time, commute time greater than 45 minutes, and number of transit stops.

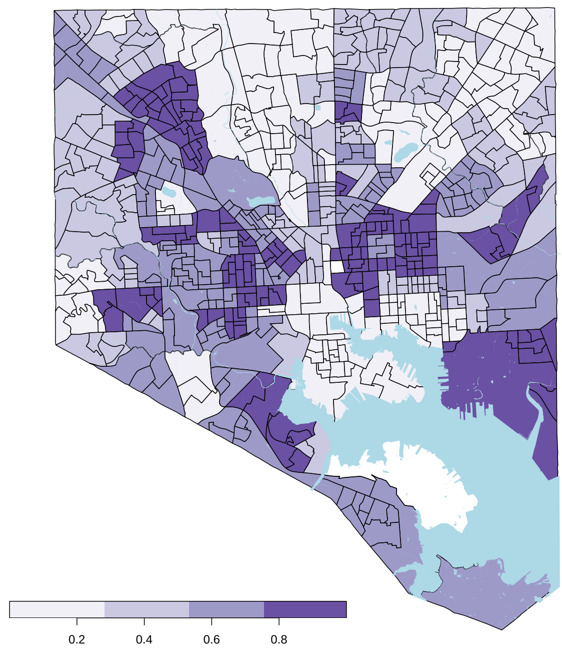
Social Vulnerability Score

The composite social vulnerability map showed the notorious 'white L' and 'black butterfly' associated with Baltimore. The lighter 'L' shape in the center of the map is mostly populated by white people and those with higher incomes, due to historic racism and redlining, while the darker colors that look like a butterfly comprise neighborhoods mostly populated by people of color and of lower income.

Social Vulnerability Indicator

Inputs

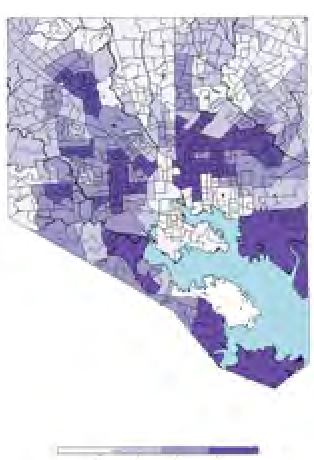
- Minority & Language Composite Score
- Sociosconomic Statue Composite Score
- Housing Type & Transportation Composite Score
- Houshold Composition & Disability Composite Score



Below, we also show the four components of the composite score so that readers can see that the same pattern holds true for all the SVI indicators, except housing type and transportation. This is likely due to many multi-unit dwellings in the downtown area, along with fewer people having cars due to their proximity to transit and many downtown amenities.

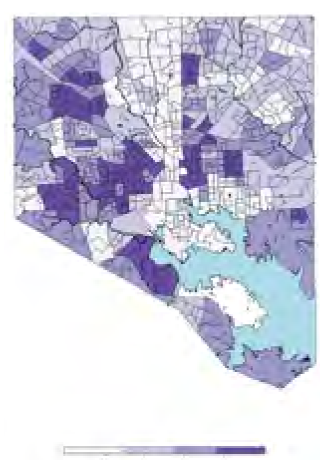
Minority Status & Language

Socioeconomic Status

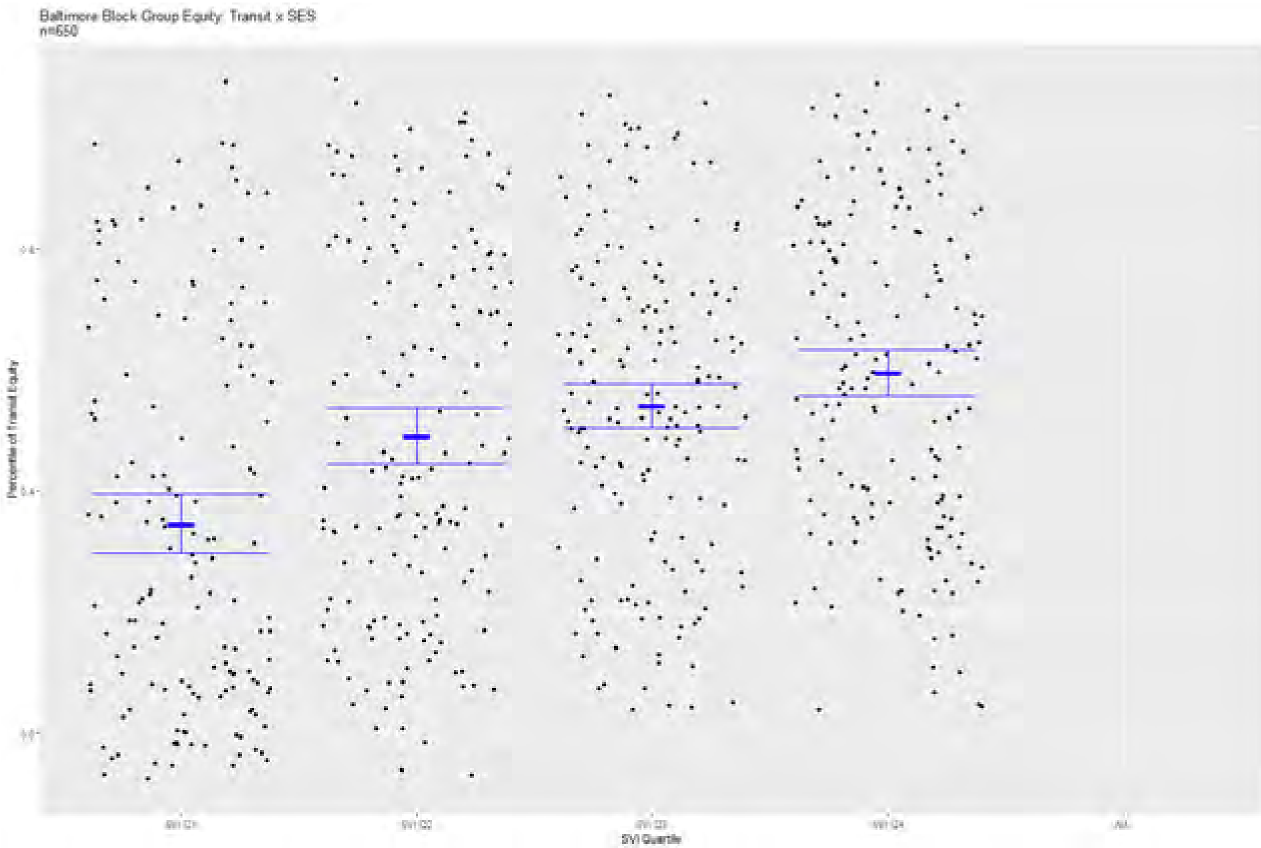


Housing Type & Transportation

Household Composition & Disability



The graph below relates the transit and social vulnerability themes, indicating that those who are more socially vulnerable also have less access to high quality transit.



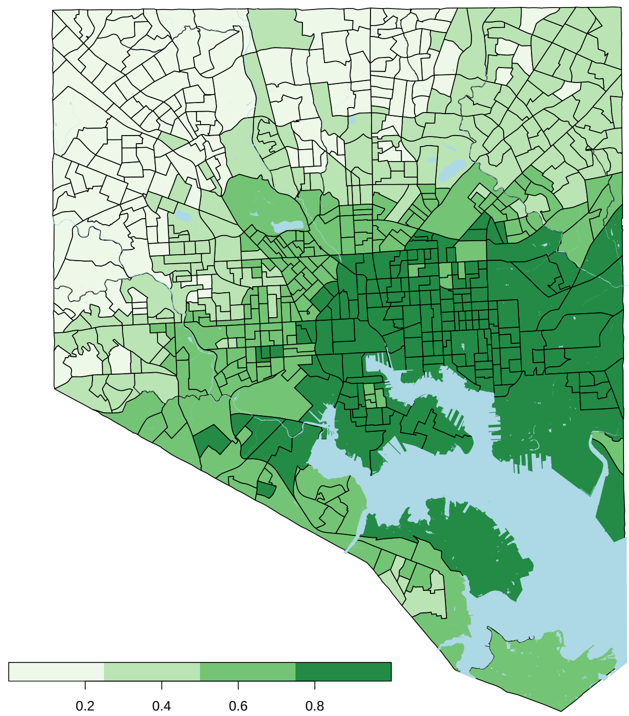
Air Quality Score

Because of EPA's measurement system for the air pollutants, patterns are more large-scale. Robust local monitoring systems could elucidate a more detailed map. According to the 2020 data, none of the measured areas were above the threshold of concern for any of these indicators set by the EPA.

Air Quality Indicator

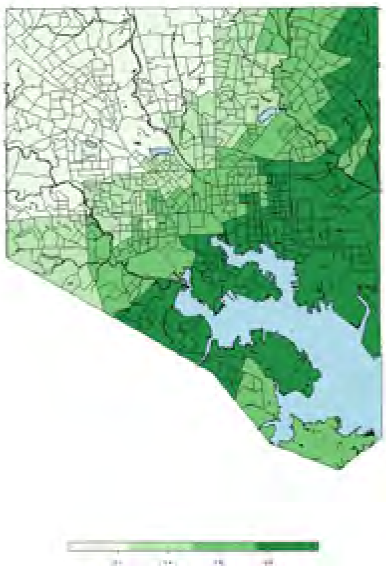
Inputs

- PM 2.5
- Ozone
- NATA Diesel PM
- NATA Respiratory Hazard Index
- Traffic Proximity

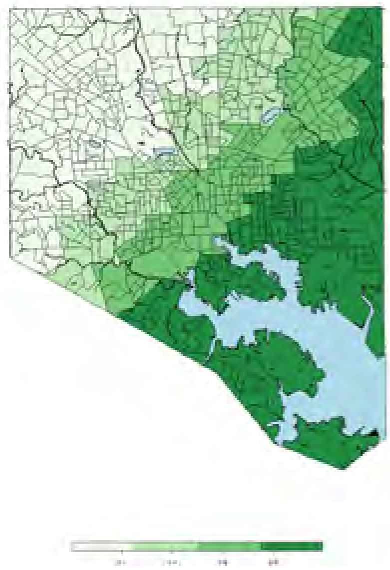


Areas close to the Patapsco River in the south east generally seem to have a higher burden of air pollution, possibly related to Baltimore's port industry emissions and the incinerator which is nearby. This concentration around the south east is especially true for PM 2.5 and Ozone. There are also higher emissions in the downtown area for diesel and overall respiratory hazard, which makes sense as it is more heavily trafficked. Finally, the traffic proximity map clearly highlights the impact of the Jones Falls Expressway heading north and the I-895 Baltimore Harbor tunnel to the east. The five maps below reflect the stratified data for each input.

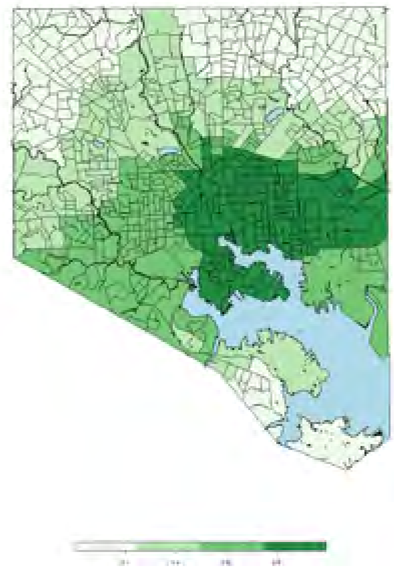
PM 2.5



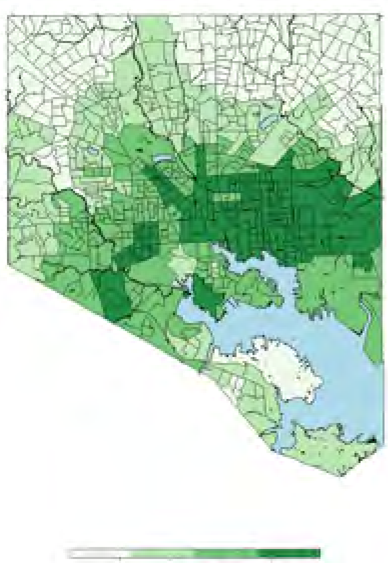
Ozone



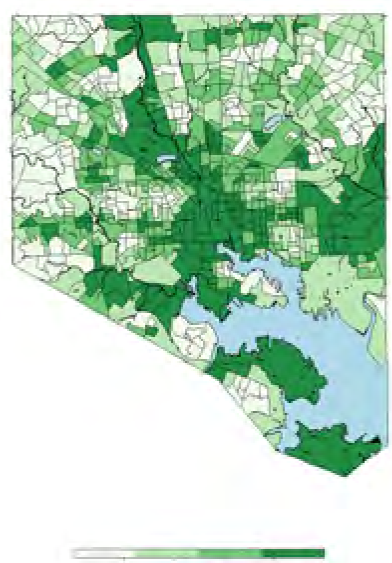
Diesel PM



Respiratory HI



Traffic Proximity



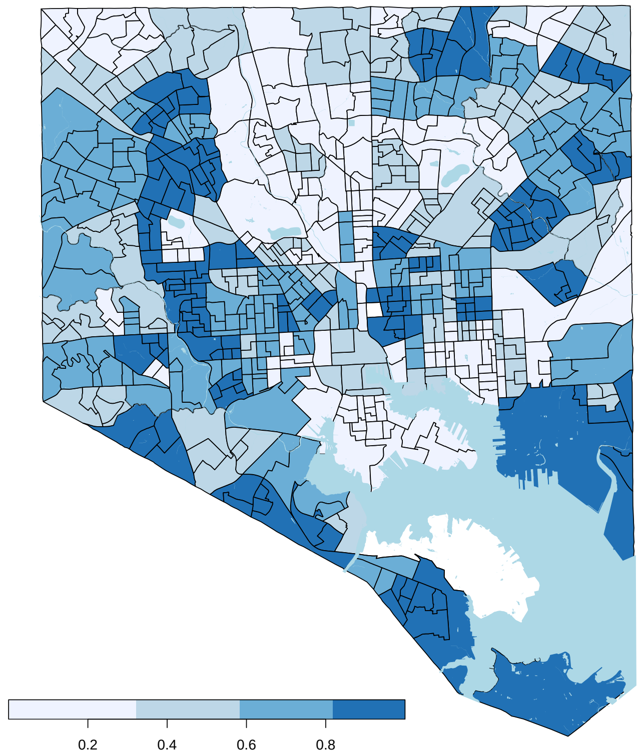
Health Score

Like the Social Vulnerability score, the composite map also suggests a pattern of the ‘white L’ and ‘black butterfly’. Areas of higher health issues also extend to the southernmost census tracts such as Hawkins Point.

Health Score Indicator

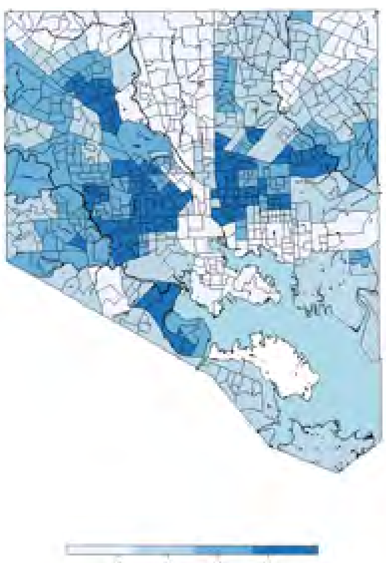
Inputs

- Asthma
- COPD
- Lung Cancer
- COVID-19
- Myocardial Infarctions
- Low Birth Weight

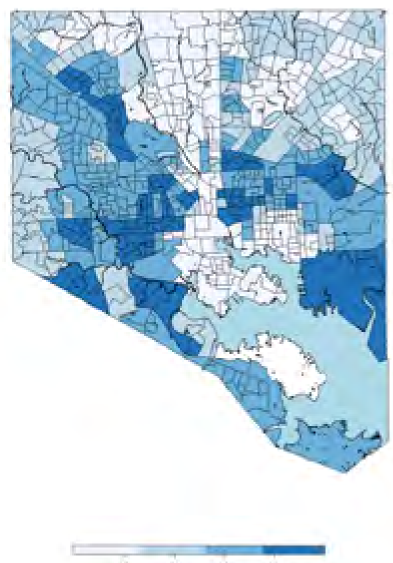


The six maps below reflect the stratified data for each input. On the stratified maps for Asthma and COPD, this distribution is consistent. We were surprised, however, that the maps for Lung Cancer, COVID-19, heart disease, and low birth weight did not follow the same pattern. There are several possible reasons for this; one being the quality of available data. As mentioned, several of these indicators are proxies. It could be that hospital discharge data selects for the population that has health insurance and access to hospitals. For COVID-19 case counts, this could be influenced by those with access to testing. Also, analyzing raw case counts does not take severity of illness into consideration, and different measures for COVID-19 that do indicate severity may follow a different pattern. More data is needed for these indicators to lead to a formal conclusion.

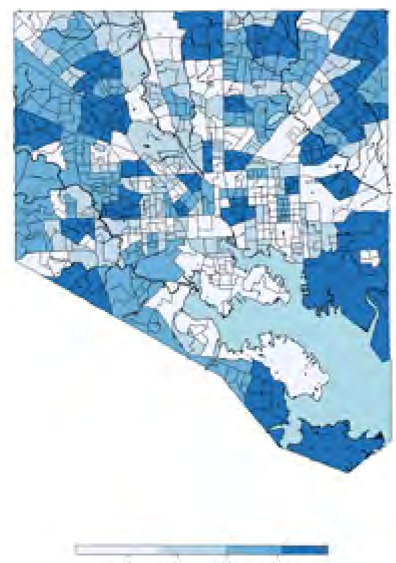
Asthma



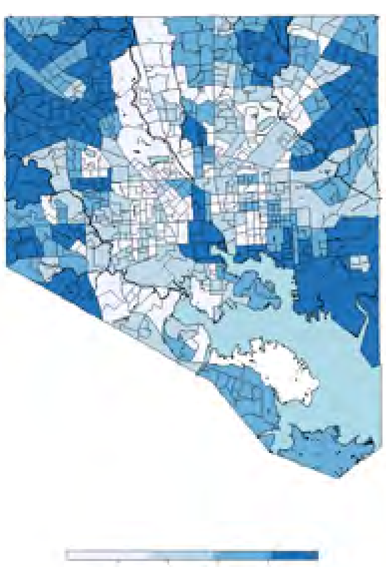
COPD



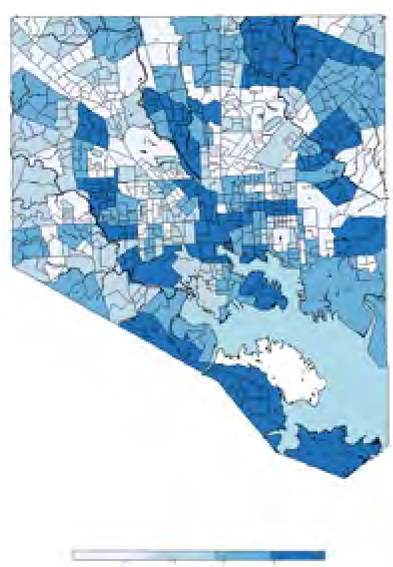
Lung Cancer



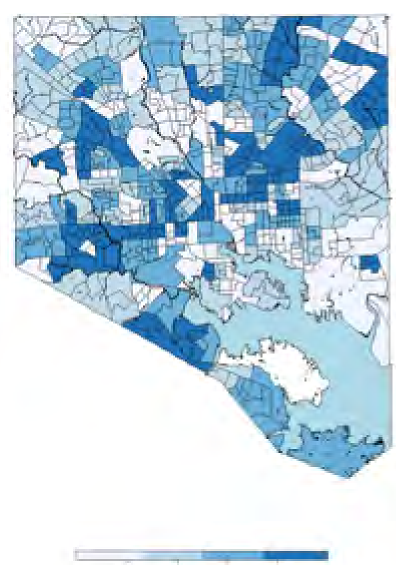
COVID-19



Heart Disease



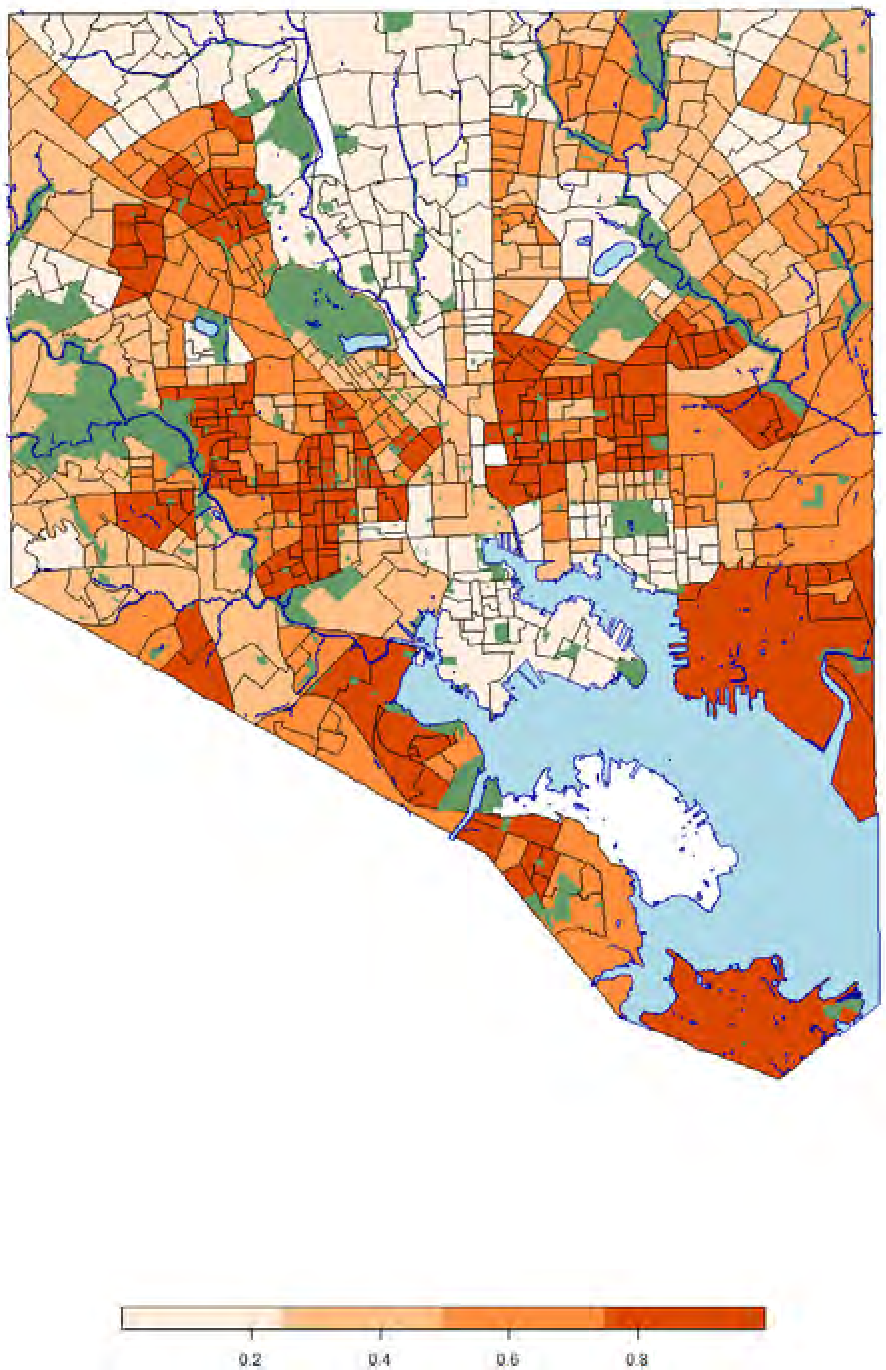
Low Birth Weight



Transit Investment Need Map

Finally, after all the data was processed using ArcGIS Pro 2.6.3 and R Studio 3.6.1, the maps were overlaid to determine which areas have the greatest need for investment (see the composite map below). The green areas indicate parks or open space and blue indicates waterways.

Composite: Areas in Highest Need (by Transit, SVI, Pollution, Health)



DISCUSSION

Transit impacts health in many ways – from the air pollution generated by the burning of fossil fuels, to reliance on cars leading to decreased physical activity, and lack of access to reliable transit having detrimental effects on mental health, as well as the ability to maintain a job or feed the family.

Public transit is an underutilized but important tool in improving community health as well as our planet's health. Using one vehicle for multiple people at a time reduces the number of vehicles in transit, and thus congestion. Such reductions can lead to fewer motor vehicle crashes and less air pollution. It also can increase physical activity as users walk (or bike) to and from public transit stops. Public transit can also increase access to parts of a region otherwise not accessible– including areas with healthy food, medical care, jobs, and education.

This is especially important from an equity perspective since low-income households are less likely to own cars and are more dependent on public transportation.[32] Communities planned around people having cars rather than people walking systemically benefit more affluent people, which in turn perpetuates racial, socio-economic, and health disparities[33]. Hence, access to public transit is a crucial determinant of health that must be studied further.

For the transit piece of this study, the focus was specifically on the accessibility and service quality of BaltimoreLink. Many assumptions were made for each topic group, as outlined in the methods section. For the transportation data, the benefit of our approach is that we used LODES data, which included fine-resolution information about the location of people's jobs and their homes. This is better than what is available from the MTA now.

With a longer project duration and the use of real-time GTFS data, the project team would most likely have documented commute times longer than estimated. In addition, our analyses would have been more robust, if stop-level, ridership, origins and destinations data had been available from MTA. In future studies of this type, we would recommend the use of bus routes and actual travel time rather than estimates. We also recommend determining which commutes exceed 90-minutes and how commute times vary for low-income jobs.

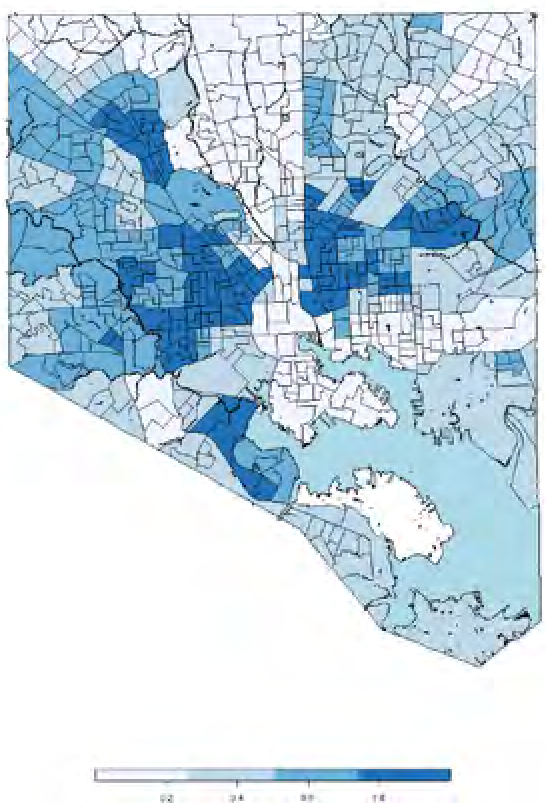
Safety data was limited to the point of excluding the theme, an opportunity for further research. Hopefully, future iterations of this report will include indicators of safety (perhaps 911 and 311 calls related to transit).

For air pollution data, more granular and local data collection is critical for elucidating air quality differences at the neighborhood level. The EPA publishes the National-Scale Air Toxics Assessment with a note about the uncertainty of air quality data: "While results are reported at the census tract level, average exposure and risk estimates are far more uncertain at this level than at the county or state level."[34]

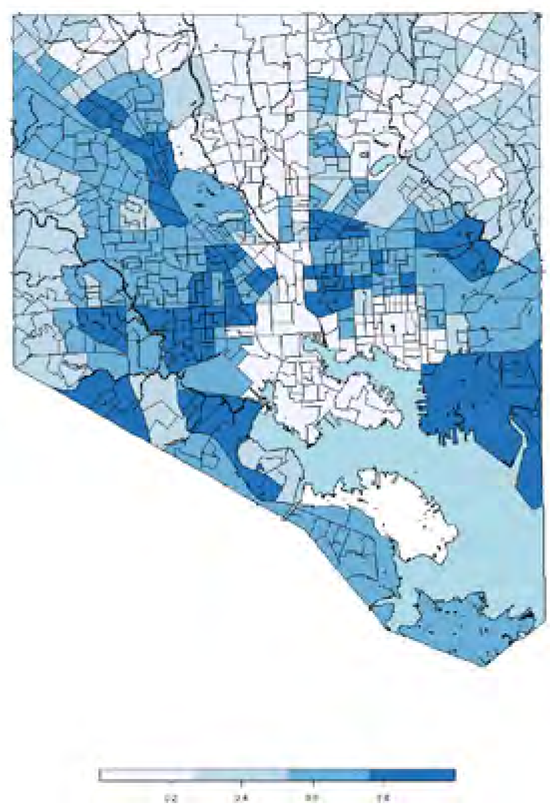
There are also notable limitations to the health data. This project's use of a multitude of information sources reflects the need for one cohesive data repository for health measures. Heart Disease and Low Birth Weight were only available in percentile format, and not at the raw data level. COVID-19 data is limited due to the new and evolving nature of the virus, and what may be inconsistencies in data collection based on race and income, but census-tract level data instead of zip code level data would be helpful for many purposes beyond this one.

Additionally, upon the recommendations of several community members, sensitivity analyses for COVID-19 and air pollution were conducted. Excluding COVID-19 from the health data to account for potential reduced testing rates in more vulnerable neighborhoods did not make a significant impact on the health outcomes map. There was some slight readjusting of neighborhoods of need in northwestern Baltimore, but not to a significant extent, as shown below.

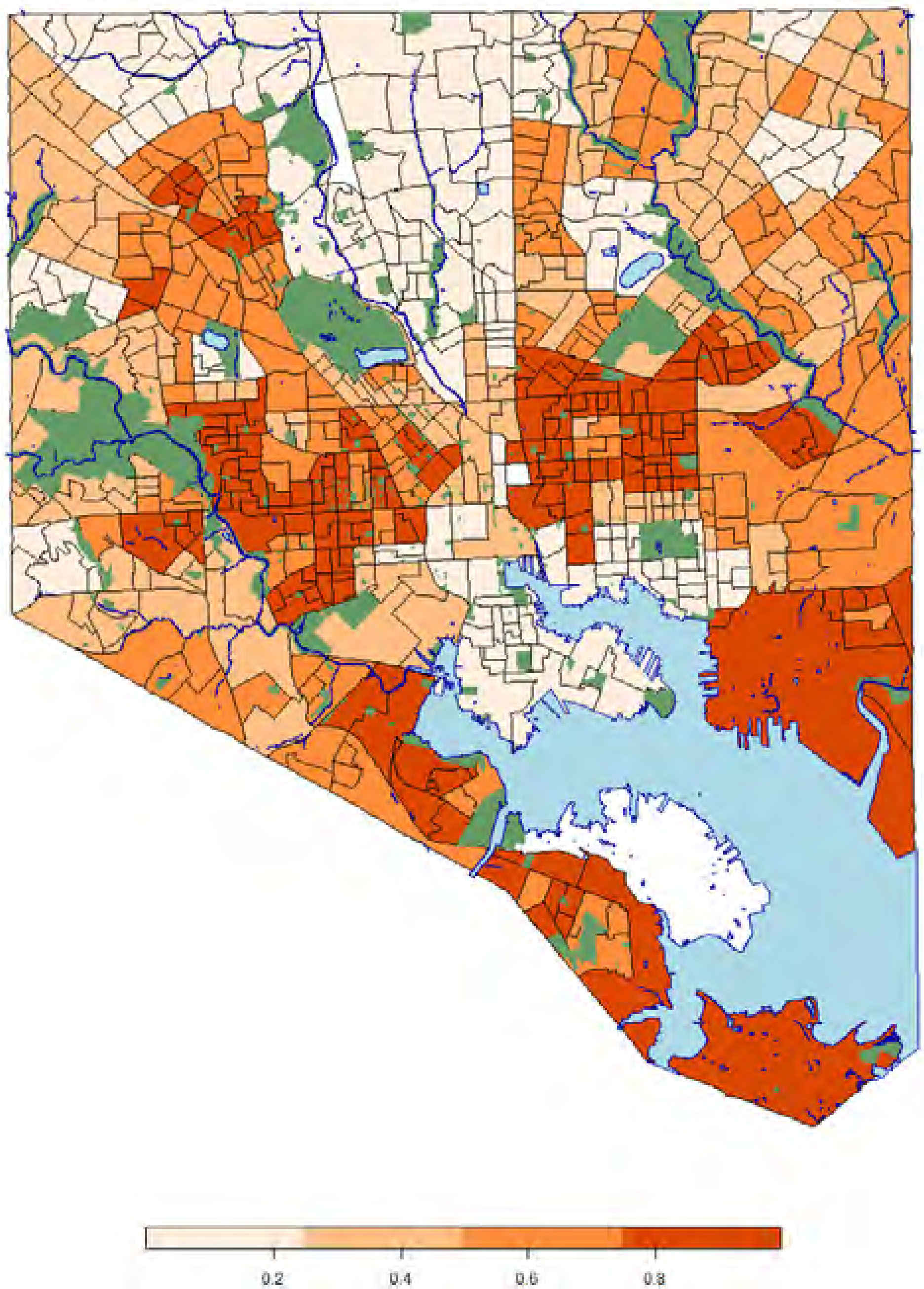
Health Equity Score to Determine Need



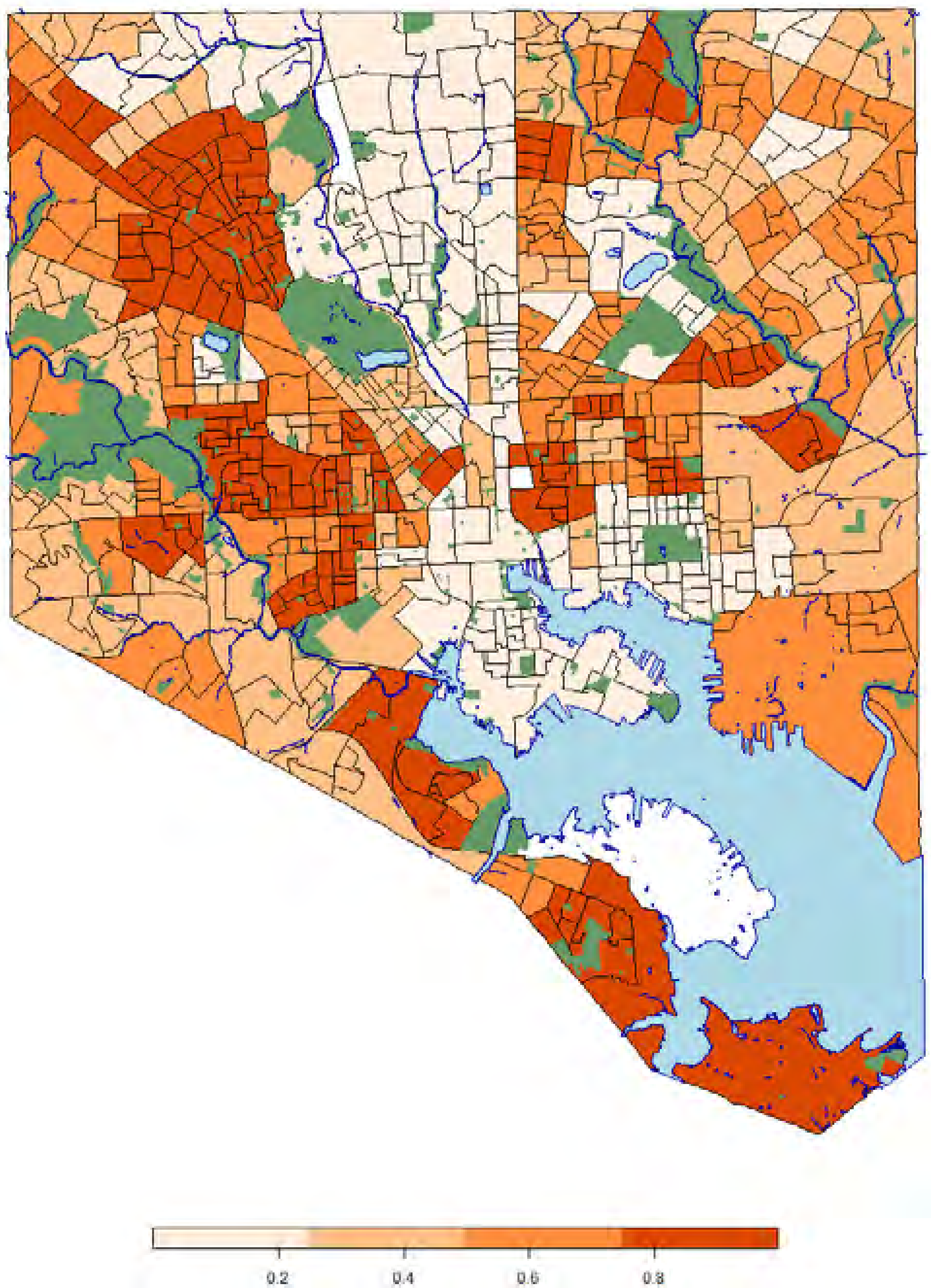
Health Equity Score to Determine Need
(excludes COVID)



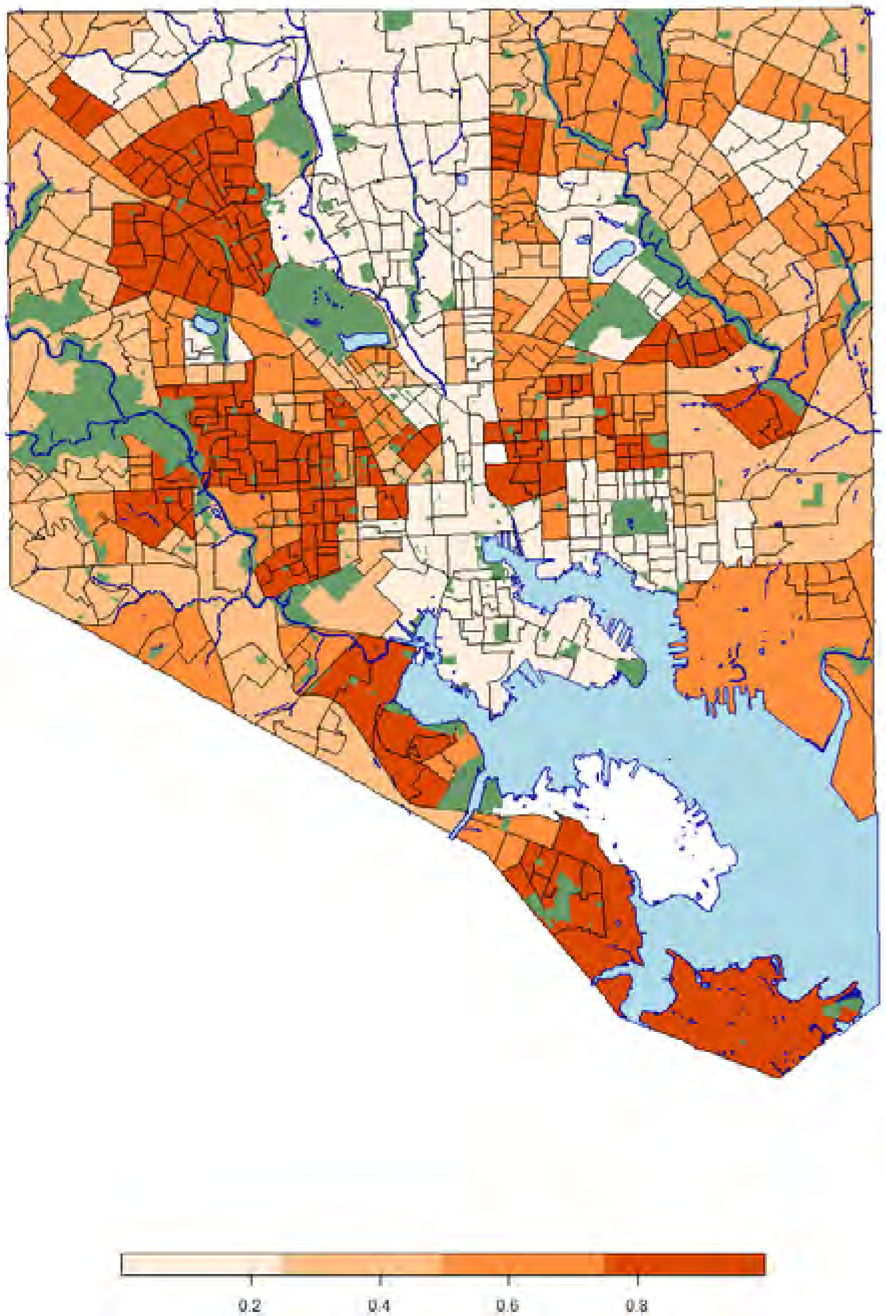
In terms of the composite map, it slightly reduced the number of high-need neighborhoods in western Baltimore, but the overall distribution remains.



With respect to the composite map, a sensitivity analysis was conducted in which air pollution data was excluded to acknowledge the fact that there are only three total air pollution monitors in Baltimore City, which does not provide adequate information at the desired granularity. This exclusion increased the number of high-need neighborhoods throughout Baltimore, as shown below.



Excluding both COVID-19 and air pollution data yields the map depicted below, which only considers transit, social vulnerability, and non-COVID-19 health outcomes. Overall, this decreases the density of high-need neighborhoods.

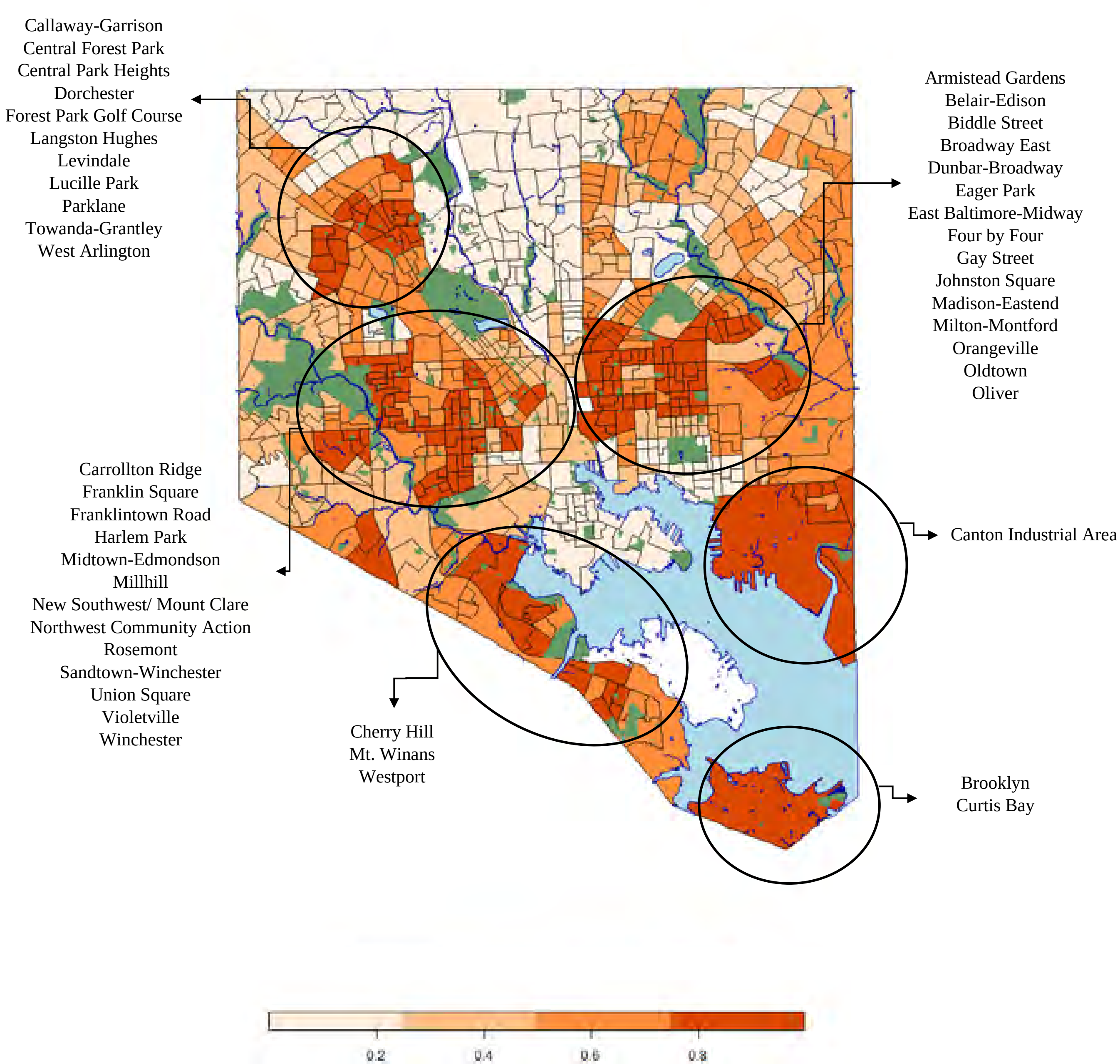


We decided to continue with the maps that included both COVID and air pollution data. This was consistent with our original goals and did not seem to change the results dramatically. However, other groups who are interested in our data and results may want to take a different approach.

RECOMMENDATIONS

The findings of this project can inform policy and investments to help alleviate the stress and undo a small part of the structural injustice woven into the fabric of Baltimore. In combination with the transit maps, it is clear that neighborhoods in the "black butterfly" with higher social vulnerability have greater need. More specifically, this indicates the potential need for greater investment in transit in the neighborhoods highlighted below:

Composite: Areas in Highest Need (by Transit, SVI, Pollution, Health)



ACKNOWLEDGEMENTS

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- Denise Griffin, Director of Arch Social Community Network
- Sharif Rashid, member of the Baltimore Transit Equity Coalition
- Robert Reuter, Vice President of the Baltimore Area Transit Association

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