# Maternal Vulnerability Index (MVI) Methodology

Developed by Surgo Ventures

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## Towards Precision Maternal Health in the US

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Towards Precision Maternal Health in the US

The United States has the highest maternal mortality among high-income countries - 17 mothers die for every 100k live births every year and rising, and Black mothers die at 2-4 times the rate of their White counterparts (Petersen, Davis, Goodman, Cox, Mayes, et al. 2019; Petersen, Davis, Goodman, Cox, Svyerson, et al. 2019). It is clear that maternal health needs attention; however, the roadmap to addressing the alarming rates and disparities in outcomes is less clear. What puts mothers at increased risk of bad outcomes? What interventions at what levels should be enacted to improve maternal outcomes?

Data gaps for both maternal outcomes and their determinants constrain making evidence-based decisions to address this crisis (Mayer et al. 2019). A growing body of evidence has found that the environment in which mothers live, work, deliver and raise their children can increase their risk of adverse health outcomes during and beyond pregnancy (Building U.S. Capacity to Review and Prevent Maternal Deaths 2018). Although data on these environmental and structural factors exist, until now there has not been one tool to bring together disparate data sources to provide county-level information on not only where, but why, mothers are vulnerable to poor outcomes. Surgo Ventures’ Maternal Vulnerability Index (MVI) fills the gap in availability of community-level data on contextual factors that systematically expose populations of mothers to environments of lower or higher risk. The MVI is a relative measure that ranks all US counties and states on how conducive the community’s environment is to good maternal health. The score ranges from 0 (the least concern) to 100 (the most concern). State and local decision makers can use the tool to better understand what puts mothers at increased risk, and where, to develop tailored, localized policy solutions. Researchers can use the MVI along with other datasets to provide a richer and more nuanced understanding of the drivers of poor maternal health outcomes.

Summary

- The MVI measures where and to what extent mothers are exposed to conditions not conducive to good maternal health in their communities
- The index is modular, to capture the multidimensional factors that contribute to maternal outcomes, including morbidity and mortality
- The index was validated using Centers for Disease Control and Prevention National Vital Statistics System (CDC NVSS) restricted data on mortality and natality; increased vulnerability is associated with higher risk of maternal mortality
- Construction of the MVI was inspired by the CDC’s Social Vulnerability Index methodology and our US COVID-19 Vulnerability Index (CCVI)

1 Though it is unclear what the driver of increasing maternal mortality is, trends can be attributed to improvements in reporting, methodological changes, and increasing prevalence of non-communicable diseases for women of reproductive age (MacDorman et al. 2016).
Index Design

Identification of maternal health drivers

We conducted a literature review to identify factors associated with maternal mortality and morbidity in the United States (expanded details of this process are in preparation for publication). Publications concerning maternal health outcomes in the United States between 2000 and 2020 were considered, including reports, working papers, books, scientific manuscripts, and review articles. Searches were conducted on Google Scholar, PubMed, and Gates Open Research. Searches were conducted on November 22-24 and December 3, 2020, with some additional literature identified throughout winter 2021. The search terms used included ‘maternal mortality’, ‘severe maternal morbidity’, ‘risk factors’, and ‘preventability’, with additional search terms used to drill down on subtopics of interest (like ‘abortion policies’). Only those publications that used statistical modeling, systematic reviews and meta-analyses that identified significant associations between systemic, community and individual-level characteristics and maternal health outcomes (morbidity and/or mortality) were included. After reviewing the literature and selecting the relevant publications, the drivers and the direction of each association were documented. The initial list of drivers was refined through an iterative consultative process. Only those with a consistent association with outcomes (as supported by empirical findings), and publicly-available datasets at the state and county levels were included. The final selection of drivers was confirmed in consultation with subject matter experts.

Thematic architecture

The MVI consists of 43 indicators associated with maternal health outcomes. Indicators were grouped into six themes, informed by Kramer et al.’s health equity framework for maternal mortality reviews (Kramer et al. 2019) and subject matter expert (SME) consultation. The six themes are:
1. Reproductive Healthcare
2. Physical Health
3. Mental Health and Substance Abuse
4. General Healthcare
5. Socioeconomic Determinants
6. Physical Environment

Reproductive Healthcare: Access to family planning and reproductive care are important determinants of maternal outcomes like mortality. The Reproductive Healthcare theme captures maternal health drivers like access to and funding for reproductive health and family planning (including abortion), availability of skilled attendants (obgyns and certified nurse midwives), and state-level reproductive rights policies.
Physical Health: A birthing person’s physical health status entering pregnancy increases their risk of pregnancy complications and/or death. This theme includes indicators of prevalence of non-communicable diseases (hypertension, obesity, and diabetes) and sexually transmitted diseases (STIs) (gonorrhea, syphilis, chlamydia, Hepatitis B, and HIV). It also includes an indicator of self-rated health.

Mental Health and Substance Abuse: Pregnancy is a period of high susceptibility when physiological changes can put birthing individuals at increased risk of mental health issues. The mental health and substance abuse theme includes indicators of frequent mental distress, prevalence of mental illness, mental health provider availability, prevalence of smoking, and drug overdose death rate.

General Healthcare: The health care system where mothers live contributes to health outcomes before, throughout, and after pregnancy. This theme captures accessibility, affordability and quality of the healthcare system, as well as preventative careseeking behaviors. Indicators in this theme are insurance coverage, primary care provider utilization, distance to the nearest hospital, the prevention quality overall composite indicator (PQI), and the state’s Medicaid expansion status.

Socioeconomic Determinants: Socioeconomic factors are known determinants of health outcomes. This theme captures educational attainment for women of reproductive age, food insecurity and poverty, English proficiency, social support, and a social capital index.

Physical Environment: The built environment is a critical factor in understanding population health status generally as well as during the pregnancy journey. This theme includes prevalence of severe housing problems, air pollution, violent crime rate, and two measures of transportation access - access to a private vehicle, and a public transit connectivity index.

Data sources

We identified data sources for each of the variables identified as drivers of maternal health outcomes at the state and county levels. Sources were selected based on their recency, completeness, geographic granularity, and the population the measure is calculated for - those specific to women of reproductive age (WRA) were preferred. Official sources that produce small area estimates and are updated periodically, such as the Census Bureau’s American Community Survey (ACS) and the National Survey on Drug Use and Health (NSDUH) were prioritized. Other indicator data sources include the Centers for Disease Control and Prevention (CDC), Guttmacher Institute, Kaiser Family Foundation, and state, and county health departments (see table 1 for data sources by indicator).

Data on WRA at the state and county levels were preferred over other populations and geographic delineations. Some indicator data was only available for populations other than
WRA, and some indicator data were only available at one geographic level of granularity (either state or county). In the absence of WRA-specific data, the available sources were prioritized with the following order: female adult population, female population, adult population, and general population. When available, both state- and county-level data were obtained. For indicators available only at the state level, the same indicator values were assigned to all the counties within each states’ boundaries. For indicators only available at the county or sub-state level, state level estimates were calculated as population-weighted means (also see Limitations).

Table 1. Maternal Vulnerability Index architecture and data sources per indicator.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Subtheme</th>
<th>Indicator</th>
<th>Population</th>
<th>Geo Precision</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reproductive Healthcare</td>
<td>Family Planning Needs</td>
<td>Female contraceptive clients served at publicly funded clinics per 100k women of reproductive age, aged 13-44</td>
<td>Women of reproductive age (aged 13-44)</td>
<td>County/State</td>
<td>(Frost, Jennifer J, Frohwirth, Lori F., and Zolna, Mia R. 2016; Frost et al. 2017)</td>
</tr>
<tr>
<td></td>
<td>Access to Abortions</td>
<td>Minimum distance to nearest abortion clinic</td>
<td>Women of reproductive age</td>
<td>County</td>
<td>(Advancing New Standards in Reproductive Health (ANSIRH) 2020)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Count of supportive abortion policies</td>
<td>General Population</td>
<td>State</td>
<td>(Nash, Elizabeth 2021)</td>
</tr>
<tr>
<td></td>
<td>Public Reproductive Health Funding</td>
<td>Public expenditures for family planning client services</td>
<td>General Population</td>
<td>State</td>
<td>(Hasstedt, Kinsey, Sonfield, Adam, and Benson Gold, Rachel 2017)</td>
</tr>
<tr>
<td></td>
<td>Reproductive Health System Capacity</td>
<td>Ratio of ob-gyn providers</td>
<td>Women of reproductive age</td>
<td>County</td>
<td>(Health Resources &amp; Service Administration, Bureau of Health Workforce, and National Center for Health Workforce Analysis 2020)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ratio of Nurse Midwives</td>
<td>Women of reproductive age</td>
<td>County</td>
<td>(Health Resources &amp; Service Administration, Bureau of Health Workforce, and National Center for Health Workforce Analysis 2020)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ratio of newborn bassinets</td>
<td>Women of reproductive age</td>
<td>County</td>
<td>(Health Resources &amp; Service Administration, Bureau of Health Workforce, and National Center for Health Workforce Analysis 2020)</td>
</tr>
<tr>
<td>2. Physical Health</td>
<td>Hypertension</td>
<td>Percent with high blood pressure</td>
<td>Adult population</td>
<td>County</td>
<td>(PolicyMap &amp; CDC BRFSS 2017)</td>
</tr>
<tr>
<td></td>
<td>Diabetes</td>
<td>Percent with diabetes</td>
<td>Female adult population (aged 20+/ aged 18+)</td>
<td>County/State</td>
<td>(United States Diabetes Surveillance System (USDSS) 2017; 2018)</td>
</tr>
<tr>
<td></td>
<td>Obesity</td>
<td>Percent that is obese</td>
<td>Female adult population (aged 20+)</td>
<td>County/State</td>
<td>(National Center for Chronic Disease Prevention and Health Promotion, Division of Nutrition, Physical Activity, and Obesity 2019;</td>
</tr>
<tr>
<td>Section</td>
<td>Indicator</td>
<td>Population</td>
<td>Geographical Level</td>
<td>Source</td>
<td></td>
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<tr>
<td><strong>Prevalence of STIs</strong></td>
<td>Prevalence of gonorrhea</td>
<td>General</td>
<td>County</td>
<td>(“National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention Atlas Plus Data” 2018)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prevalence of primary or secondary syphilis</td>
<td>General</td>
<td>County</td>
<td>(“National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention Atlas Plus Data” 2018)</td>
<td></td>
</tr>
<tr>
<td><strong>Self-Rated Health</strong></td>
<td>Percent reporting poor or fair health</td>
<td>Adult</td>
<td>County</td>
<td>(Behavioral Risk Factor Surveillance System (BRFSS) 2018b)</td>
<td></td>
</tr>
<tr>
<td><strong>Stress</strong></td>
<td>Percent reporting frequent mental distress</td>
<td>Adult</td>
<td>County</td>
<td>(Behavioral Risk Factor Surveillance System (BRFSS) 2018a)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percent with a long commute (&gt;30 minutes)</td>
<td>Female</td>
<td>County/State</td>
<td>(US Census Bureau 2020)</td>
<td></td>
</tr>
<tr>
<td><strong>Mental Health Status</strong></td>
<td>Percent reporting any mental illness</td>
<td>Adult</td>
<td>County</td>
<td>(National Survey on Drug Use and Health 2020)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percent ever diagnosed with depression</td>
<td>Adult</td>
<td>County</td>
<td>(PolicyMap &amp; CDC BRFSS 2018)</td>
<td></td>
</tr>
<tr>
<td><strong>Accessibility</strong></td>
<td>Mental health providers</td>
<td>General</td>
<td>Countyb</td>
<td>(CMS, National Provider Identification 2020)</td>
<td></td>
</tr>
<tr>
<td><strong>Substance Abuse</strong></td>
<td>Percent that smoke</td>
<td>Adult</td>
<td>County</td>
<td>(County Health Rankings &amp; BRFSS 2018)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age adjusted overdose death rate</td>
<td>General</td>
<td>County/State</td>
<td>(PolicyMap &amp; CDC NCHS 2017)</td>
<td></td>
</tr>
<tr>
<td><strong>Affordability</strong></td>
<td>Postpartum extension status</td>
<td>General</td>
<td>State</td>
<td>(Henry J Kaiser Family Foundation 2021a)</td>
<td></td>
</tr>
<tr>
<td>5. Socioeconomic Determinants</td>
<td>Income eligibility limit for pregnant individuals</td>
<td>Pregnant individuals</td>
<td>State</td>
<td>(Brooks et al. 2021)</td>
<td></td>
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<tr>
<td>Medicaid expansion status</td>
<td>General population</td>
<td>State</td>
<td></td>
<td>(Henry J Kaiser Family Foundation 2021b)</td>
<td></td>
</tr>
<tr>
<td>Percent who are uninsured</td>
<td>Women of reproductive age (aged 19-44)</td>
<td>County/State</td>
<td></td>
<td>(US Census Bureau 2020)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accessibility</th>
<th>Distance to nearest hospital</th>
<th>General population</th>
<th>County/State</th>
<th>(Homeland Infrastructure Foundation-Level Data 2020)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Careseeking Behavior</th>
<th>Percent that reported a routine physical checkup</th>
<th>Adult population</th>
<th>County</th>
<th>(PolicyMap 2018a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent that reported having a primary care provider</td>
<td>Adult population</td>
<td>County</td>
<td>(PolicyMap 2018b)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quality</th>
<th>Prevention Quality Indicator (PQI)</th>
<th>Adult population</th>
<th>State/County</th>
<th>(&quot;Prevention Quality Indicator (PQI), 2018” 2020)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Educational Attainment</th>
<th>Percent with a bachelor’s degree</th>
<th>Women of reproductive age (aged 25 and older)</th>
<th>County/State</th>
<th>(US Census Bureau 2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent with no high school degree</td>
<td>Women of reproductive age (aged 18-44)</td>
<td>County/State</td>
<td>(US Census Bureau 2020)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minority Status</th>
<th>Percent that speaks English less than well</th>
<th>General population</th>
<th>County/State</th>
<th>(US Census Bureau 2020)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Poverty</th>
<th>Percent that live under poverty</th>
<th>Women of reproductive age (aged 15-44)</th>
<th>County/State</th>
<th>(US Census Bureau 2020)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Food Insecurity</th>
<th>Percent suffering from food insecurity</th>
<th>General population</th>
<th>County</th>
<th>(C Gundersen et al. 2020)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Social Capital</th>
<th>Percent that are single female headed</th>
<th>Households</th>
<th>County/State</th>
<th>(US Census Bureau 2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social capital index</td>
<td>General population</td>
<td>County</td>
<td>(&quot;The Geography of Social Capital in America&quot; 2018)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Housing</th>
<th>Percent with severe housing problems</th>
<th>Households</th>
<th>County/State</th>
<th>(Comprehensive Housing Affordability Strategy (CHAS) 2013; 2014; 2015; 2016; 2017)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Violence</th>
<th>Violent crime rate</th>
<th>General population</th>
<th>County</th>
<th>(Federal Bureau of Investigation 2017; Office of Justice Research and Performance 2021)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Transportation</th>
<th>Percent with no access to a vehicle</th>
<th>Adult female population (aged 16 and older)</th>
<th>County/State</th>
<th>(US Census Bureau 2020)</th>
</tr>
</thead>
</table>
Data preprocessing

Missing data treatment

Missing data was treated according to the type of missingness, including: non-existence, suppression and non-reportage. The first type of missingness was non-existence and primarily affected capacity indicators (like ob-gyn availability). These were addressed by calculating accessibility proxies using alternate geographic delimitations - 2010 Economic Areas by the Bureau of Economic Analysis (BEA2010). When appropriate, missing values of this type were zero-imputed. For suppression and non-reportage that coexisted and were, in some cases, indistinguishable we (a) characterized the geographic patterns and affected percentage of the US population, and (b) supplemented with alternative data sources (e.g. small-area estimations from PolicyMap or violent crime rates for New York City). If alternate sources were not available, (c) sparse indicators (missing for geographies with 20% of the population or more) were dropped. The remaining missing values were addressed with multiple imputation (described in the next subsection).

Multiple imputation

One indicator had missing values at the state level, and ten indicators had missing values at the county level. In each county and state with a missing value for any indicator, the general population and the population of women of reproductive age (WRA) were determined to better understand what percentage of the total US general and WRA population were affected by missing values. Counties with missing values tended to be small in terms of both general and WRA population size: indicator values were missing for <1% of the general and WRA populations. Missing data was imputed using the classification and regression trees method (CART) in the ‘mice’ R package (van Buuren and Groothuis-Oudshoorn 2011), with 50 iterations, a random seed, and a correlation threshold of 0.3. MICE is a multiple imputation method used to replace missing data values in a data set under certain assumptions about the data missingness mechanism (e.g., the data are missing at random, the data are missing completely at random). This process involves first fitting a statistical model for each variable and each imputation; then, imputations are drawn from each fit and the data are updated. All the indicators included in the index were used as covariates for the
imputation. The convergence and densities of the imputed dataset were inspected for outliers but none were found.

Software

Data carpentry and statistical analyses were carried out in R Statistical Software (R Core Team 2021).

Index calculation

The overall MVI and thematic MVI scores were calculated at the state and county levels to rank each state or county on a scale of 0-100 in vulnerability to adverse maternal health outcomes (0 = least vulnerability, 100 = most vulnerability). Similar to how the Centers for Disease Control and Prevention Social Vulnerability Index is calculated (Flanagan et al. 2011), we followed a stepwise ranking process to generate the vulnerability scores with equally-weighted indicators:

1. Raw indicator values were multiplied by the valence of the relationship between each driver and maternal health outcomes (e.g. hypertensive disorders put mothers at increased risk of maternal death, valence is +1).
2. Valence-multiplied indicator values were percentile-ranked.
3. Indicator-level percentile ranks were aggregated to the sub-theme level as an additive subtheme score.
4. Subtheme scores were percentile ranked.
5. Subtheme-level scores were aggregated to a theme-level score.
6. Each aggregate theme score was percentile ranked against all other geographies, resulting in 6 thematic scores (on a scale of 0-100) for each geography.
7. Thematic scores were aggregated into an overall MVI score.
8. Overall MVI scores were percentile-ranked.

Geographic locations were generally classified as experiencing very low (vulnerability score <20), low (20-40), moderate (40-60), high (60-80), and very high (80-100) vulnerability to negative maternal health outcomes. Other cut-offs used to ease the visualization and interpretation of results will be specified appropriately under each analysis.

Validation

The predictive power of the index was validated against CDC’s NVSS restricted data on natality and mortality (National Vital Statistics System, National Center for Health Statistics, Centers for Disease Control and Prevention, 2020). We found that mothers living under higher MVI scores were at increased risk of maternal death. This pattern held for each of the thematic scores; higher vulnerability due to overall and each of the six MVI themes was
associated with increased risk of death. The validation analysis has been submitted for CDC's approval, and cannot be shared publicly until it is obtained.

Analysis

Race/ethnicity

To make our analyses investigating racial/ethnic differences in maternal vulnerability comparable to existing literature in maternal health, when possible, we use the following race and ethnicity categories: ‘American Indian/Alaska Native’, ‘Asian’, ‘Black’, ‘Hispanic or Latino’, ‘Pacific Islander’, and ‘White’. Hispanics or Latinos of any race and origin are included in ‘Hispanic or Latino’, and Native Hawaiians are included in the ‘Pacific Islander’ category. Each race category includes individuals of Hispanic and Non-Hispanic ethnicity. When referencing external data, race/ethnicity categories from the original data source were used (e.g. in the data source for U.S. MMRs by race/ethnicity ‘Asian or Asian American’ and ‘Pacific Islander’ are grouped into ‘Asian American or Pacific Islander’).

Maternal Mortality Ratio calculation

Unless noted otherwise, MMRs used in maternal vulnerability analyses and validation were calculated using publicly available NVSS natality and mortality datasets (United States Department of Health and Human Services (US DHHS), Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS), Division of Vital Statistics, 2020; Centers for Disease Control and Prevention, National Center for Health Statistics, 2020) as

$$MMR = \frac{100,000 \times \text{maternal deaths}}{\text{live births}}$$

where maternal deaths are defined as deaths with an underlying cause of death classified under ICD-10 codes A34, 000–095, or 098–099, for individuals under 45 years old following Hoyert (2021) and CDC's recommended age cut-off for maternal mortality (National Center for Health Statistics, Centers for Disease Control and Prevention n.d.).

Limitations

- The MVI is a comparative metric that ranks the vulnerability of every US geographic unit against each other (i.e. a county against all other counties, a state against all other states). The index is not an absolute measure of vulnerability.
- The index is modular and uses a single weighting scheme for indicators applied across the whole U.S. However, the influence of individual themes on vulnerability might vary geographically.
● The MVI was developed through a literature review of empirical evidence, theoretical frameworks of maternal health, and expert consultation. While the direction of some associations with negative maternal health outcomes have been established (e.g. older age generally increases the risk of ill maternal health), some remain poorly understood.

● The index assigns one score per theme to each county. In the U.S, counties are heterogeneous, and the county or state levels may mask inequities within counties. For example, some indicator values like public transit availability or violent crime rates may vary significantly at more detailed geographic scales such as neighborhood or census tract.

● The index was built with existing datasets available for the whole US. Missingness levels varied by indicator, by theme, as well as by geographic level of analysis. Some indicator data were not available at county-level, and missing values were substituted with multiple imputation; missing values disproportionately affected counties with smaller populations.

● Because the index relies on datasets available for the whole US, the index may not capture state-specific programs put in place to mitigate negative maternal health outcomes (like the California Maternal Quality Care Collective).

● There are discrepancies nationally in maternal morbidity and mortality surveillance and reporting – not all definitions are the same, and not all states identify cases in the same way, leading to subpar national maternal mortality data. Although these data are not optimal, they are the best available, and the index was validated using these data.

● The index only covers 50 US states and the District of Columbia (the US territories were excluded), but the methods and approaches are applicable to all geographies, provided maternal health drivers are identified and data to measure them exists.

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Pulkit Agarwal, Jordan Downey, Bettina Hammer, Peter Smittenaar, and Valerie Valerio.

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