THE IMPACT OF RURAL HOSPITAL-BASED MATERNITY UNIT CLOSURES IN NORTH CAROLINA

Kathleen E. Knocke

A dissertation submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Health Policy and Management in the Gillings School of Global Public Health.

Chapel Hill
2022

Approved by:

Kristin Reiter

Martha Carlough

Leah Frerichs

Kristen Hassmiller Lich

Emma Sandoe

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ABSTRACT

Kathleen E. Knocke: The Impact of Rural Hospital-Based Maternity Unit Closures in North Carolina
(Under the direction of Kristin Reiter)

North Carolina has experienced more than eight hospital-based obstetric unit closures since 2015. Maternity care is an essential health care service, and maternity unit closures often leave rural patients without regional access to timely maternity care. Hospital-based maternity care unit closures can result in longer travel times, high-risk births, and poor perinatal outcomes for the surrounding community. This mixed-methods study uses system support mapping, random forest models, and quantitative analysis to examine factors that influence travel time to care, maternal morbidity, and maternal death after childbirth in communities that have experienced a hospital-based maternity care unit closure.

During the system support mapping interviews (n=13), travel time issues were especially prominent for women with other children, pets, or without family in the area in rural maternity unit closure communities. Important factors influencing the care experience included the availability of mental health support, travel distance to appointments and the hospital for the delivery, relationships with their provider, and community integration. Relative variable importance derived from the random forest model suggests characteristics of the beneficiary (age and Medicaid coverage type), the community in which the beneficiary lives, and the amount of observation time (via prenatal care or after-delivery observation) are the most predictive factors of severe maternal morbidity. The event study with nearest neighbor matching compared travel

time and maternal death following delivery. Findings suggest the closure type, whether the entire hospital or maternity unit only closed, affects communities differently. Complete hospital closures were associated with maternal death, and maternity unit-only closures were associated with longer travel times. Rurality was increasingly associated with longer travel time, and race and rurality jointly were positively associated with longer travel times in some cases.

This study provides support for community or beneficiary-targeted interventions to improve maternal health outcomes. Rural hospitals with closed maternity units may benefit from training to prepare for maternity care emergencies that present in the emergency room.

This dissertation is dedicated to my partner, Chris.

ACKNOWLEDGEMENTS

Thank you to the following for their support and expertise throughout my doctoral program:

Family and Friends

Dissertation Chair and Committee

Doctoral Program Cohort

North Carolina Rural Health Research Center

Department of Health Policy and Management Faculty

Interview Participants and Recruitment Partners

Federal Office of Rural Health Policy

North Carolina Office of Rural Health

North Carolina Translational and Clinical Sciences (NC TraCS) Institute

Carolina Cost and Quality Initiative

Cecil G. Sheps Center for Health Services Research

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LIST OF ABBREVIATIONS

AI	American Indian
AIM	Alliance for Innovation on Maternal Health
AN	Alaska Native
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
CNM	Certified Nurse Midwife
COVID-19	Coronavirus Disease of 2019
CPT	Current Procedural Terminology
DRG	Diagnoses Related Groups
FORHP	Federal Office of Rural Health Policy
ICD	International Classification of Diseases
ICD-10-CM	International Classification of Diseases 10th Edition Clinical Modification
ICD-9-CM	International Classification of Diseases 9th Edition Clinical Modification
MMRC	Maternal Mortality Review Committees
NC	North Carolina
NPI	National Provider Identifier
OB/GYNs	Obstetricians and Gynecologists
PCS	Procedure Coding System
QI	Quality Improvement
RMAPS	Rural Maternity Care Experience Study
ROC	Receiver Operating Characteristic
RUCA	Rural-Urban Commuting Area
SVI	Social Vulnerability Index

INTRODUCTION

With rising maternity mortality and morbidity rates in the United States, providing evidence-based and guideline-concordant maternity and perinatal care is imperative (1). Studies have attempted to identify the impact restricted maternity care access for rural residents has on patient outcomes, health care costs, and rural communities, but the intricacy of the rural health service infrastructure poses unique challenges (1-3). North Carolina has experienced eight[1] hospital-based obstetric unit closures since 2015 (4). Maternity care is identified as an essential health service, and maternity unit closures often leave rural patients without regional access to timely maternity care (5, 6). Hospital-based maternity care unit closures can result in longer travel times, high-risk births, and poor perinatal outcomes for the surrounding community (7). Additionally, hospital maternity care unit closures can interfere with prenatal and postpartum care, increasing travel distances and barriers to meet timely and necessary appointments critical to meeting maternity milestones (2, 8).

The interdependency among parts of the maternity care system and necessary coordination of care over the course of a woman's[2] pregnancy, delivery, and postpartum care makes this study crucial and its application of a mixed-methods system-based approach novel. To advance the long-term goal of understanding the impact hospital-based maternity unit

[1]This statistic undercounts the number of maternity unit closures that have occurred in North Carolina because it does not include urban hospitals, maternity care units that have reopened, or maternity units that have closed because the entire inpatient unit of the hospital closed.

[2]Gendered language is used throughout for consistency to the study population in each of the aims, however, we recognize the issues discussed in this paper are experienced by all birthing persons regardless of identity, sexuality, or orientation.

closures have on patient experiences, care seeking behavior, and maternal morbidity, the application of a system science perspective allows us to identify critical relationships and emergent effects among the various components of the rural maternity care system. Systems science is an interdisciplinary field dedicated to investigating complex systems and the interaction between the heterogeneous components of the system (9). Maternal care includes prenatal care, labor and delivery, and postnatal care provided by multiple practitioners at multiple physical locations. Significant system-level barriers exist for rural women and women of color when accessing appropriate and timely maternal care (10-12). The purpose of this study is to leverage system science methods to explore rural patients' experiences with the maternity care system over the course of their pregnancy, delivery, and postnatal care, identify predictive factors of severe maternal morbidity, and estimate the impact of rural maternity unit closures on maternal health outcomes.

To better understand the impact of maternity unit closures on maternal outcomes in North Carolina, this study explores the following aims in a mixed methods exploratory sequential study:

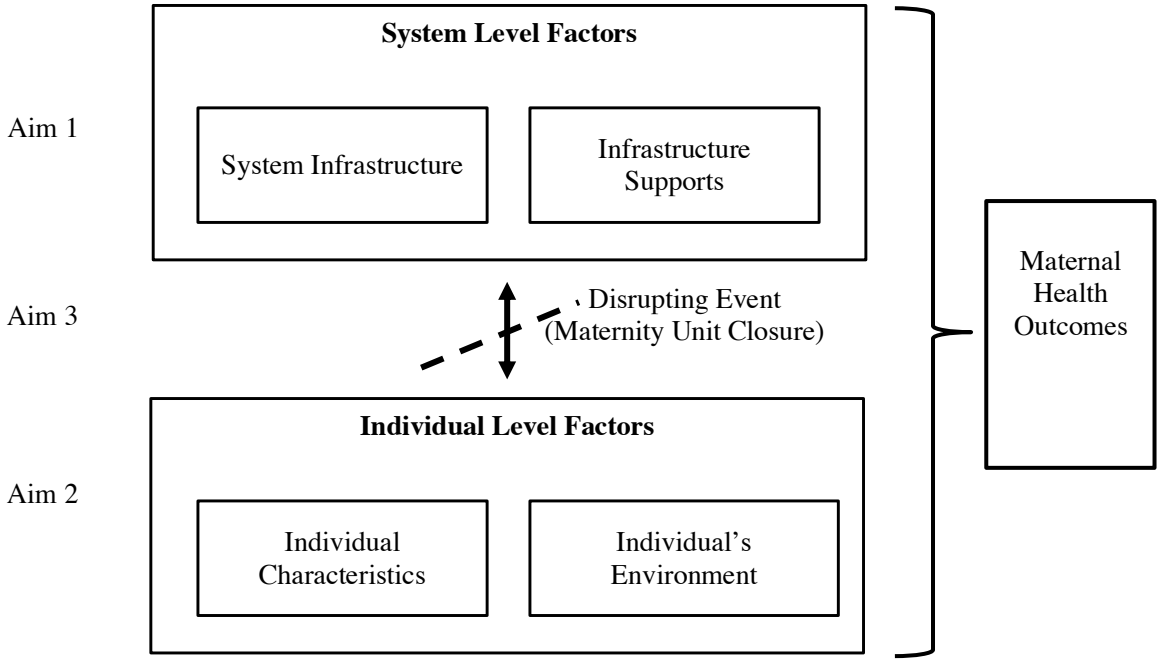
Aim 1: Describe key maternal system features essential to supporting rural maternal care. Interview participants will use system support mapping to identify system elements accessed by the individual during their maternity care experience.

Aim 2: Identify key patient-level factors related to patient maternal morbidity. Using tree-based machine learning models to understand the relative importance of factors that affect maternal morbidity, I will identify the most important patient level factors that predict maternal morbidity.

Aim 3: Assess the effect of maternity unit closures on maternal morbidity and timely maternity care. The effect of a maternity unit closure will be estimated using difference in differences methods and nearest neighbor matching between rural women from communities that experienced a maternity unit closure and communities that did not.

This study explores the impact of both system level factors and individual level factors on maternal outcomes (Figure 1). In Aim 1, individuals will describe their experience navigating the maternity care system identifying the elements of the system (system infrastructure) and how individuals were supported accessing them. Aim 2 uses patient-level claims data to identify patient-level factors that predict maternal morbidity. Finally, Aim 3 focuses on how maternal outcomes are affected by a local maternity unit closure (i.e., a disrupting event that poses threats to how individuals navigate the system).

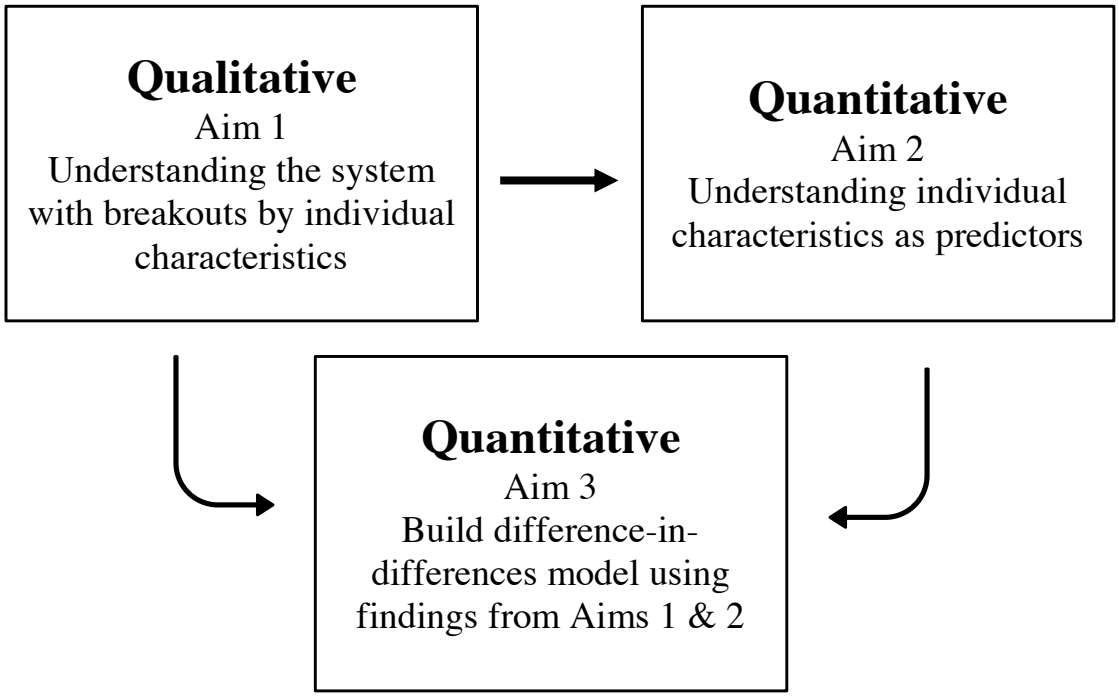
FIGURE 1: CONCEPTUAL MODEL DETAILING STUDY RELATIONSHIPS.



This proposed study leverages a mixed methods design to ground the study findings in patient experience and identify limitations in administrative claims data (Figure 2). For example,

familial support may play an important role for some women over the course of their maternity care; however, this information will not be present in the administrative data used in the quantitative aims. Aims will be completed in sequential order as the results of each Aim describe different pieces of the maternity care system in rural communities. The services and timing of services received over the course pregnancy through the postpartum period (i.e., dose of care) remains an understudied factor on the pathway to improving maternal outcomes. By considering all maternity-related visits over an individual's pregnancy, we are using a broader set of events to track patient utilization to provide a more nuanced understanding of how variation in care utilization and timing affects maternal outcomes.

FIGURE 2:DEPICTION OF THE MIXED-METHODS STUDY DESIGN.



Qualitative data was obtained from participants during system support mapping activities conducted virtually with participants over Zoom. Quantitative data came from North Carolina Medicaid administrative claims that occurred between January 1st, 2011 and December 30th,

2019, accessed through the Carolina Cost and Quality Initiative. Medicaid is the primary payer for rural births, but Medicaid coverage ends for new mothers in states without Medicaid expansion 60 days after delivery (13, 14). This policy can make the coordination of postpartum care more difficult and unaffordable, despite the importance of postpartum care to preventing maternal morbidity and mortality. The quantitative sample will be constructed from North Carolina Medicaid claims data with delivery codes. Medicaid beneficiary profiles were created with claims one year before and after the triggering event (i.e., delivery) to include prenatal, delivery, postpartum care. Women recruited for qualitative interviews in Aim 1 will also be restricted to deliveries in this time period for consistency across aims. Construction of the closure communities will also be the same across all Aims by using the same collection of hospital market area zip codes and list of closures.

This study is the first application of system science methods to understand maternity care. Systems science offers the unique ability to draw connections to elements over time and identify feedback loops within the maternity system that impact maternity outcomes directly and indirectly. The systems mapping exercises, causal loop diagrams, and descriptive analysis will provide needed context to inform future research. Given the health disparities among rural women and other subgroups, simulation modeling will be an important tool to estimate the effect certain policies and interventions will have to improve maternal outcomes. A deep understanding of the maternity system, how the system usage and components differ among patient subgroups, and how patients move through the system are important steps towards a simulation model. The findings of this study can be used to build a system dynamics model to simulate outcomes, test hypotheses, and find new solutions to the rising maternal morbidity rates in the US.

AIM 1: A QUALITATIVE STUDY OF MATERNITY CARE SUPPORTS IN RURAL NORTH CAROLINA COMMUNITIES

Background

For the past 30 years, maternal mortality has been increasing in the United States. Recent research finds rural mothers have a nine percent greater probability of experiencing severe maternal mortality and morbidity than urban mothers (8, 15). Of all the maternal mortality deaths in the US, more than 60 percent are preventable if appropriate and timely medical services are available (2). Simultaneously, rural hospitals have closed their maternity care units across the US – over half of all rural counties do not have an obstetrics unit (16). In North Carolina, there have been 8[3] hospital-based obstetric unit closures since 2015 (4). As more rural hospitals stop providing maternity care services each year, rural women have expressed growing anxiety surrounding their maternity care and where they will give birth (1, 2). After some rural hospital closures, news headlines detailing up to 100-mile trips to the nearest delivery unit highlight the widening geographic gaps in rural maternity care (11, 17).

Thus far, the majority of maternity unit closure research has been focused on patient perspectives and attitudes towards the closure of these units and studies that identify how rural maternity unit closures affect maternity care at the system level have not been updated or reexplored to reflect the current realities of rural maternity care in the United States. With robust

[3]This statistic undercounts the number of maternity unit closures that have occurred in North Carolina because it does not include urban hospitals, maternity care units that have reopened, or maternity units that have closed because the entire inpatient unit of the hospital closed.

maternity care infrastructure, maternity unit closures left patients to the "vagaries of practitioner's attitudes," feeling unsupported in their communities and by their providers, and experiencing more barriers to care (18-20). The primary purpose of this study is to identify specific system supports and navigation challenges for women who live in rural communities. Second, this study will explore differences in reported supports and challenges between women who experience a hospital-based maternity unit closure and women who reside in communities where local maternity services remain. As part one of a three part exploratory sequential mixed-methods study, hypotheses generated from this study will inform variable selection in subsequent quantitative papers examining the impact of maternity unit closures on maternal health outcomes.

Methods

Participants were recruited through multiple mediums to engage in short, recorded interviews (video conference or telephone), participants completed a system support mapping activity describing supports and challenges they experienced throughout pregnancy and delivering in rural communities. This study was approved by University of North Carolina at Chapel Hill Institutional Review Board (20-2337).

Participants and Recruitment

We used convenience sampling methods to recruit participants. Recruitment materials were developed under the brand of the Rural Maternity Care Experience Study (RMAPS) (Appendix 2). Informational flyers about the study were created for print and electronic distribution via email through professional networks, hospitals, and across the UNC system. The flyers were shared via email to maternity care providers at rural North Carolina hospitals, University of North Carolina maternity care-related departments, and through professional

networks. Facebook and Instagram accounts under the RMAPS brand were also created to join social media groups across rural communities in North Carolina and direct social media advertising was used to direct potential participants to the recruitment screener and additional information on the study through the RMAPS website. The use of multiple platforms was intended to create recognition and credibility for the study and promote participation via multiple engagements with the recruitment materials. Given the potentially sensitive information participants would discuss in an interview about their maternity care experience, we felt the effort to reach participants through their care providers, community pages, and other trusted sources would result in more engagements with the materials.

Recruitment materials included either a QR code or link to access a Qualtrics screener and list of eligibility criteria to build a pool of potential participants with personal contact information (Appendix 3). In order to assess inclusion/exclusion criteria, the screener included questions about potential participants' month and year of delivery, and zip code of residence at the time of delivery. Other supplementary information for analysis included gender identity, race and/or ethnicity, type of insurance (if any), and preferred method of contact.

Inclusion Criteria

Participant delivery dates were required to be within the window of January 2011 and December 2019. This period was chosen to align with the complementing years of Medicaid data available for the subsequent aims of the RMAPS study, and to ensure the 60 days of postpartum coverage for beneficiaries with Medicaid for Pregnant Women allowed after a delivery on December 31, 2019 would end prior to the start of the Coronavirus-19 pandemic in March 2020 (addressing system barriers related to COVID-19 and the provision of maternity care were out of scope for this study).

Participants were required to reside in a rural location as designated by the Federal Office of Rural Health Policy (FORHP) definition. The FORHP definition of rural considers zip codes located in non-metro counties, metro census tracks with non-metro Rural-Urban Commuting Area (RUCA) codes, and metro RUCA codes with at least 400 square miles in area with a population density of 35 or less per square mile as rural zip codes. This definition is appropriate in this study because the unit of analysis is consistent across all aims in the mixed-methods study, and the definition aligns organizations that would be eligible for rural-focused grants (21). Furthermore, zip codes meeting the rural criteria were further classified as 'rural, non-closure community' or 'rural, closure community'. The list of rural hospitals with closed obstetrics units was compiled in coordination with academic colleagues, the North Carolina Office of Rural Health, and confirmation using Medicaid administrative delivery claim billing codes. A complete list of rural hospitals that closed maternity care units according to the study criteria is included in Appendix 4. Of note, we did not include maternity-unit closures that occurred as part of a complete hospital closure because this type of closure would affect a broader spectrum of care services and objectives. In this study, we defined communities that experienced a hospital-based maternity unit closure as the collection of residential household zip codes of Medicaid beneficiaries who delivered at the hospital prior to the closure of the unit. The zip codes associated with each closure were further restricted by requiring zip code centroids to be within 60 miles, consistent with the author's previous work calculating maximum travel distances for delivering women before and after maternity unit closures.

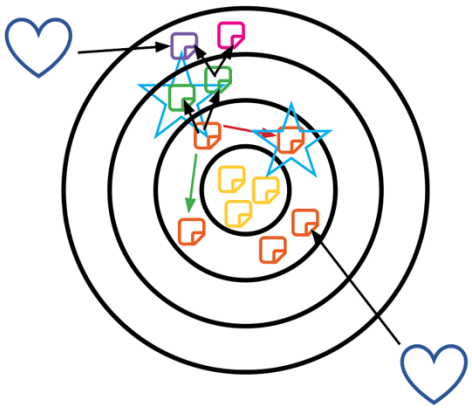
Potential participants with residential zip codes meeting FORHP rural criteria but in which there was no maternity unit closure will be referred to throughout this paper as individuals from "rural only communities," and those with zip codes that meet FORHP criteria and appear in

the pool of zip codes that delivered at a to-be-closed maternity care unit will be referred to as individuals from "closure communities." Individuals who delivered within the six-months preceding a closure of their local maternity unit discussed the closing of the unit and noted changes that were already taking place at the hospital; thus, we categorized these individuals as residing in closure communities even though they delivered prior to the closure.

Procedures - System Support Mapping

We used system support mapping as a tool to conduct structured interviews. System support mapping is a tool used to systematically gather information from individuals in unique but related roles within a system (i.e., managers or administrators) and identify gaps, needs, and facilitating elements within a system. As developed, system support mapping consists of four concentric circles where participants describe their roles, responsibilities, needs, resources, and wishes within the context of the system. Elements in each circle are connected to denote related elements across the circles, highlighting how the system, or collective of interconnected parts, operates under a common objective (22).

FIGURE 3: EXAMPLE OF SYSTEM SUPPORT MAPPING DIAGRAM



Rather than focusing on the roles of individuals, in this study the system support mapping process was adapted to be place-based (Figure 3). Instead of discussing their roles and

responsibilities within a system, women were asked to recall their maternity care experience and identify the places, services and care objectives they expected at each place, and the supports and challenges that affected the provision of each service. Given the emotional connection individuals have towards the overall birthing process, the maps are centered on the description of each individual's overall sentiment towards the pregnancy, delivery, and postpartum journey. At the end of the interview, participants were asked to identify changes they wished for and the places and services that they were the most thankful for. An interview guide with ring descriptions, prompts for each circle, and process documentation is included in Appendix 1.

Data Collection

Participants were interviewed for up to 45 minutes via a recorded Zoom or telephone call. Interviews were performed between August 13, 2021 and October 8, 2021. The sequencing of each interview was guided by a checklist to review introductory materials, consent forms, and verify information from the screener. A script with introductory explanations, prompts, and follow-up questions for each ring provided consistency in data collection across participants.

The system support mapping template was created in the collaborative platform Miro with labeled circles and color-coded blank sticky notes. As each participant discussed the objectives and stories related to each ring and made connections, the interviewer completed the map elements in real-time and asked participants to review for correctness and completeness. Individuals residing in closure communities were asked to confirm whether they were aware of a maternity unit closure in their community and whether they would have gone to that hospital if it was open. For participants unable to access a screen, additional time was allotted to repeat to the participant the items written down in the mapping process. One participant chose not to share their screen. Recordings were transcribed using built-in transcription software in Zoom.

Data collection stopping criteria identified *a priori* required a minimum of two participants to discuss each identified place from both the rural only and closure community groups or have at least eight, and up to twenty, interviews per closure group. Advertising and outreach efforts ended when stopping conditions were met, and the remaining individuals in the Qualtrics pool of participants were scheduled for interviews. Participants were offered a $20 e-gift card to Amazon or Wal-Mart delivered to their email address as a thank you incentive for their time and participation at the end of the interview. Funding for the e-gift cards was provided by the University of North Carolina at Chapel Hill Department of Health Policy and Management.

Analysis

Throughout the coding synthesis and analysis process, interview transcriptions and recordings were reviewed to capture quotes, assess sentiment, and verify coding synthesis decisions. Using the export function of Miro, each map was converted to text in a comma-separated value file. Text was recategorized by the corresponding ring (i.e., places, care objectives, etc.) because color-coding is stripped in the conversion to text, and linked concepts on the map were arranged into a table of pathways – one row for each pathway. Each place and service or care objective combination was assigned a pathway number, along with the corresponding supports, challenges, wishes, and impactful supportive services. Demographic information from each participant's screener, a map number, and whether the participant was in a rural or closure community were included with each pathway. Interview transcripts and recordings were referenced when additional context was needed to appropriately complete a pathway and identify quotes to include in the write-up.

Codes were consolidated to standardize language within rings in cases with slight phasing and word choice differences to obtain a list of codes that each represented a unique concept. A second round of thematic coding across the consolidated codes further reduced the list of codes. For example, the determinants were reduced from 165 initial codes to 68 determinants (see Table 1). Frequencies for each place and service combination across the maps were tabulated using the list of codes after the consolidation process. Themes were then compared across rural only and closure groups to identify any patterns and shared experiences common among each group. Frequencies for each place and service combination across the maps were tabulated using the resulting standardized codes.

TABLE 1: TABLE OF EXAMPLE STANDARDIZED DETERMINANT CODES AND SECOND-ROUND CODES.

Standardized Code	Second Order Code
few providers in the area	limited provider availability
limited days and times provider is in town	limited provider availability
providers unable to take on new patients	limited provider availability
new care established late in pregnancy with new provider	care not consistent or coordinated
office closed and given list of new providers to go to	care not consistent or coordinated

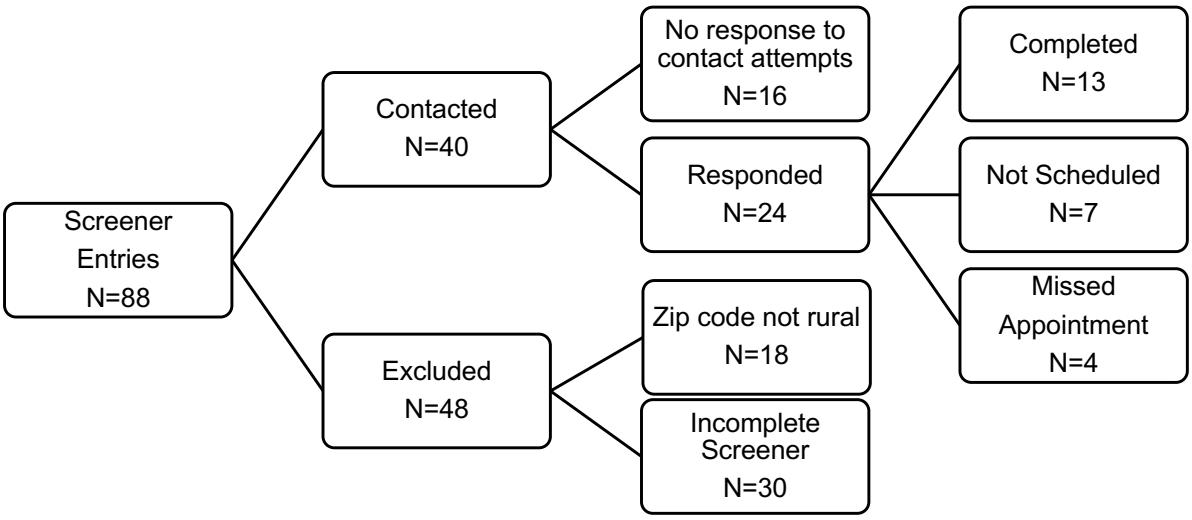
When participants detailed challenges and supports related to a service, some services appeared to be 'inflection points' in the maternity care system. In this study, inflection points are defined as system elements that were characterized as a barrier by one participant and a facilitator by another. These characterizations of system elements also invoked strong emotions and sentiments in participants as they described their experiences and therefore served as turning points or "inflections" in the overall maternity care journey. During analysis, these moments were identified when more than one participant discussed the same system element with distinct and opposite differences in sentiment and tone surrounding the experience.

Results

Participants

Of the 88 responses captured through the participation screener, 40 responses met all eligibility criteria (i.e., complete contact information, residing in a rural zip code, and delivery between January 2011 and December 2019). The primary reason for exclusion was incomplete information, including missing contact information, and 18 responses did not meet the FORHP definition of rural. Of the forty potential participants who were contacted, 23 did not respond to either the initial contact or scheduling attempts, and four individuals did not show up to the interview appointment – resulting in 13 completed interviews in the final sample (Figure 4).

FIGURE 4: FLOW DIAGRAM OF THE POOL OF PARTICIPANTS THROUGH THE RECRUITMENT, CONTACT, AND INTERVIEW PROCESS. OF THE 88 SCREENER ENTRIES GATHERED THROUGH QUALTRICS, 13 PARTICIPANTS WERE ULTIMATELY INTERVIEWED AND INCLUDED IN ANALYSES.



Five participants delivered in communities after the closure of their local hospital-based maternity unit and two individuals delivered within the six-month window leading up to the closure of their local maternity unit. All five participants from closure communities confirmed the closure of the hospital closest to their residence. Because both individuals who delivered within the six-months preceding a closure discussed the closing of the unit and noted changes

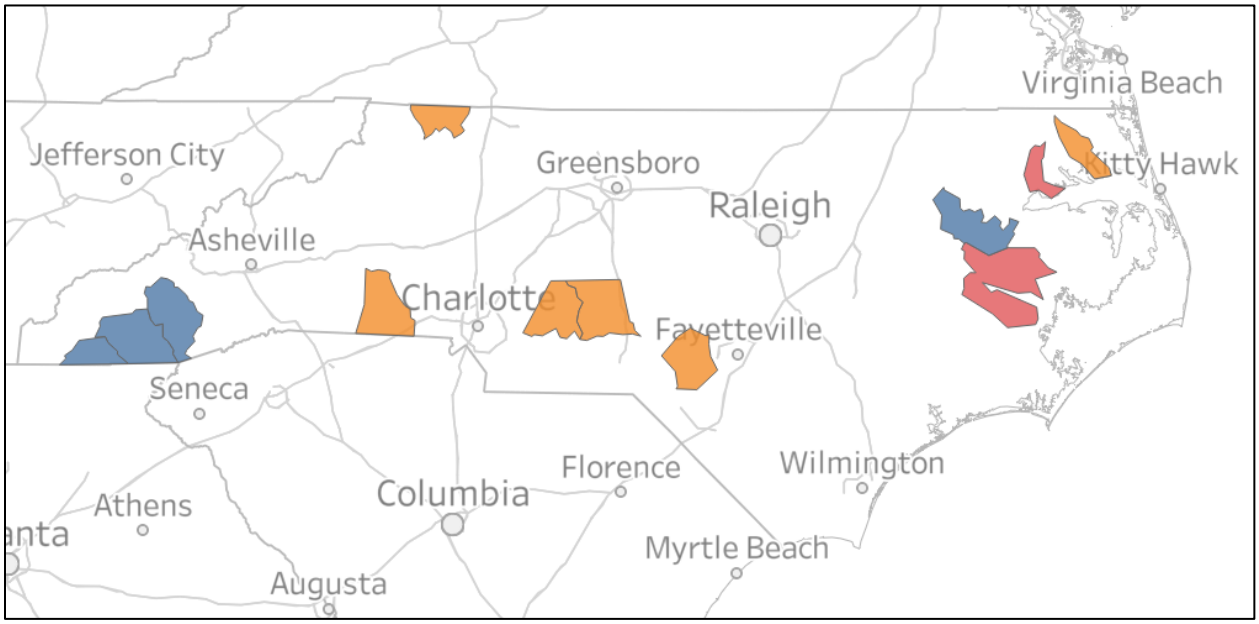
that were already taking place at the hospital, we categorized these individuals as residing in closure communities. Six participants delivered in rural only communities. Among all participants, seven had private insurance and six had Medicaid, and the majority were White (N=8) (Table 2). The 13 study participants resided in 12 unique counties across North Carolina (Figure 5). The closure community individuals are clustered around two hospital-based maternity unit closures, one in the mountainous western region of North Carolina and one in the Northeast region, and rural only individuals largely resided in central counties.

TABLE 2: DESCRIPTION OF PARTICIPANTS INCLUDED IN THE STUDY (N=13).

Participant Characteristics	N=13
Analysis Group	
Maternity Unit Closure	7
Rural, No Closure	6
Insurance Type	
Private Insurance	7
Medicaid	6
Race	
White	8
Black	4
Native American	1

Note: The two individuals who delivered in the months preceding the closure of their local maternity unit were included in the maternity closure group because both individuals acknowledged changes in services available at the hospital.

FIGURE 5: MAP OF THE THIRTEEN PARTICIPANT COUNTIES OF RESIDENCE AT THE TIME OF DELIVERY. PARTICIPANTS RESIDED IN TWELVE UNIQUE COUNTIES ACROSS NORTH CAROLINA.



Places and Services

Participants each identified between 8 and 20 unique pathways with an average of 16 pathways per map. Of all pathways, the hospital and obstetrics and gynecologist provider offices were the most frequently identified places in pathways (31% and 19% of all pathways respectively) and were identified by most participants (12 of 13 and 9 of 13 participants, respectively). Other key places important to the maternity care experience identified by the majority of participants were the pediatrician's office of their newborn, places in the community in which they lived (i.e., local businesses, their children's school, church, etc.), their homes, and their places of work (Table 3).

TABLE 3: COMPILED LIST OF PLACES AND SERVICES RECEIVED AT EACH PLACE DESCRIBED BY PARTICIPANTS DURING THE SYSTEM SUPPORT MAPPING ACTIVITY.

Place and Service Combinations	
Place	**Service**
Hospital	Birthing Classes
	Place of Delivery
	Lactation Consultation
	Nursery Services
	Postpartum Care
	Birth Pre-registration
	Prenatal Care
	Source of community support
Home	Familial Support
	Home Monitoring
	Postpartum Care Visits
	Source of community support
	Spousal Support
	Place of Delivery
Obstetrics and Gynecology Provider	Prenatal Care
	Lactation Consultation
	Genetic Screening
	Present at Delivery
	Recommendations and Referrals
	Mental Health Screening
Pediatrician	Well-baby Visits
	Mental Health Screening for Mother
	Visits for older children
Primary Care Provider	Pregnancy Confirmation

	Postpartum Care
	Annual Visits
Insurance	Recommendations and Referrals
Health Department	Prenatal Care
	Postpartum Care
	Pregnancy Confirmation
	Sugar Testing
	Mental Health Screening
Community	Daycare and Support for Other Children
	Hosted Support Groups
	Transportation To and From Appointments
	Recommendations and Referrals
Doula	Source of Community Support
	Present at Delivery
	Lactation Consultation
	Postpartum Care
Midwife	Source of Community Support
	Present at Delivery
	Lactation Consultation
	Prenatal Care
	Postpartum Care
Neonatal Intensive Care Unit	Newborn Care
Work	Leave Approval
	Source of Community Support
Therapist	Hosted Support Group
	Individual Therapy
Church	Recommendations and Referrals

	Source of Community Support
	Hosted Support Group
Maternity-Adjacent Services	Chiropractor
	Physical Therapy

Of the 13 participants, four individuals had scheduled caesarian deliveries, four individuals had scheduled inductions, three had spontaneous deliveries in hospitals, and two planned to deliver in their home. Individuals insured through Medicaid were the only participants to include their local health department in their list of places, and the health department was identified by individuals from both rural only and closure communities.

All participants received prenatal care services, and 11 of 13 received postpartum services. The majority of participants delivered at hospitals. Services related to work (e.g., requesting time off for appointments, parental leave, postpartum support, etc.) were more often described by participants residing in closure communities. Participants also identified sources of emotional and logistic support as well as recommendations and referrals to other services, resources, or providers throughout their maternity care. The location of where individuals identified prenatal care services varied across four places (hospital, physician office, midwife home visit, and health department) and three types of trained providers and birth workers (physician, midwife, and doula).

Both closure and rural only communities had similar proportions of identified challenges and supports, and participants from both groups identified more barriers than facilitators. A full table of thematic categories discussed by two or more individuals is included in Table 4. Themes discussed as both challenges and supports are also included in Table 4 and discussed below in further detail (see Inflection Point section). Provider availability for appointments and between visit questions and having the participant's provider present at the delivery were the most

frequently identified maternity care supports. Travel distance to providers and maternity care facilities was identified as a barrier for four women in closure communities compared to one woman in the rural only community group. Women in rural only communities described more difficulty planning out logistics and finding community support. In contrast, women in closure communities said they needed the entire day off work for appointments and were anxious about being away for long periods if they delivered in a hospital; however, women in closure communities did not need to plan detailed logistics as they were not going to be in their community for extended periods. Being disconnected from a support system, having a negative relationship with their provider, family-unfriendly practice policies (e.g., not allowing kids in provider offices and not allowing family to be present at the birth), and unaddressed mental health concerns were the most frequently discussed barriers in both groups.

TABLE 4: LIST OF DETERMINANTS DESCRIBED BY AT LEAST TWO PARTICIPANTS OR THAT ARE RELATED TO AN INFLECTION POINT. DETERMINANTS ARE SORTED BY ANALYSIS GROUP AND WHETHER THE PARTICIPANTS IDENTIFIED THE DETERMINANT AS A BARRIER OR FACILITATOR.

Determinant	Closure Community	Rural Community	Total
Facilitators Identified by Participants			
"Extra Mile" Bedside Manner	2	0	2
Provider Present at Delivery	4	2	6
Provider Support Between Visits	2	1	3
Connected to Community Support	2	2	4
Provider availability	4	2	6
Familial Support (other than Spouse)	2	1	3
Felt Informed and Prepared for Appointments	3	0	3
Parental Leave Support	1	1	2
Preferred Family and Friends at Delivery	5	2	7
Appreciated Provider Knowledge	1	2	3
Mental Health Sufficiently Addressed	2	2	4
Sincere Relationship with Provider	3	1	4
Spousal Support	3	0	3
Travel Distance	1	2	3

Work was Flexible for Appointments	2	1	3
Facilitator Totals	**37**	**19**	**56**
Barriers Identified by Participants			
Provider Absent During Delivery	2	0	2
Anxiety Throughout the Pregnancy Over Lack of Local Maternity Care	2	0	2
"Assembly Line" Relationship with Provider	1	2	3
Birth Plan Changed*	3	1	4
Maternity Care Uncoordinated	3	0	3
Conflict with Practice or Facility Policies	2	3	5
Conflict with Provider	1	2	3
Delivered Without Preferred Friends and Family	3	0	3
Unaddressed Pain	1	1	2
Disconnected from Community	3	3	6
Difficulty Planning Because of Logistic Constraints	1	4	5
Felt Unprepared and Uniformed	0	3	3
Financial Constraints*	0	2	2
Choice Limitations Via Insurance*	2	1	3
Limited Provider Availability for Appointments	3	2	5
Mental Health Unaddressed	3	1	4
Limited Provision of Services*	2	6	8
Lack of Transportation Options*	1	1	2
Travel Distance	4	1	5
"Uncomfortable" with Care Received	1	3	4
Work-Related Issues	2	2	4
Barrier Totals	**40**	**38**	**78**

Note: Starred barriers do not have a complementing facilitator. Interviewees did not share facilitators related to paying for care, insurance, and the breadth of options available.

Wishes and Stars

Wishes expressed by participants followed four themes: desire for closer facilities, access to maternity support services such as transportation, greater autonomy and choice, and strong support networks.

Closure Facilities

Five participants expressed a desire for a provider facility within 10-15 minutes, a sentiment that was not exclusive to closure communities. All individuals who delivered with other providers wished their prenatal care provider had been present at the delivery. Participants also wished for more information and consultative services during the postpartum period, as noted by the interviewee below.

> "I would change postpartum care one visit at six weeks. That's not good enough. You're a mess. You feel like you were hit by a dump truck. Your hormones are everywhere. Your body's not right. Things happen when you're breastfeeding. There's infections and rashes… They just had me come for one six-week postpartum visit, and they were like, you're done."

Maternity Support Services

Related, participants wished for cheaper public transportation options, especially for individuals who could not drive, had to pay for public transportation, and/or needed to pay for parking at all appointments. Paying for gas and access to comfortable transportation during emergency scenarios (i.e., labor or painful complications) were also cited as a transportation barrier. Even for those with personal and private transportation, one participant recalled, "riding home in the car for two hours with a newborn and a postpartum pelvic situation sucked, and the mountains… you know, you're bleeding at that point… the drive back was miserable." Other maternity support services wished for by participants included continuously available breastfeeding consultations and circumcision services at the hospital. - These were unavailable for two participant-infant dyads who delivered on the weekend. For women who chose to receive maternity care outside of a medical office (i.e., with a birth center or midwife unaffiliated with an obstetrics practice), they wished for friendlier and more lenient medical office polices because they had difficulty making appointments with medical providers for laboratory services and medical concerns that occurred in the postpartum period because they "didn't give birth with them."

Greater Autonomy and Choice

For both rural only and closure communities, participants noted a lack of options for providers and facilities. For example, one participant described a negative experience with her provider, who was the only maternity care provider within an hour radius. Thus, the participant was hesitant to initiate prenatal care for their current pregnancy. Generally, individuals wanted options and to have a sense of autonomy over their care rather than being "boxed-in." Participants preferred to have a single provider handle all maternity care, and many wanted a doula or midwife present at the birth, especially in the event of a cesarean delivery. Two individuals expressed a desire to have more control over their laboring process (e.g., shower, walk around, use an exercise ball, stand up, etc.), and two other individuals wished their providers had been more attentive to the needs they expressed during their deliveries.

> "I didn't have any control over the way that I got to labor. They didn't let you get up and walk around, use a yoga ball, get in the shower. They were like, get in the bed and shut up."

Two other individuals wished providers made fewer assumptions about their knowledge and awareness during and after the delivery process. For example, providers assumed one mother knew how to control the analgesia pump and assumed another mother would not have breastfeeding difficulty because she had prior births. One participant delivered in a hospital without a nursery and remembered, "So after you have a cesarean section, the baby is in the room with you... it's like good luck Sis. I love my kids… but holding a newborn when you can't feel your body from the chest down, it's scary."

Additionally, insurance network restrictions, public transportation options to care, office hours of operation outside of work hours, pregnancy risk factors, provider preferences, and facility policies (e.g., whether children were allowed in the provider office during obstetric visits) were contributors to a sentiment of restriction and lack of autonomy. In one case, a

woman was denied a request to have her tubes tied, recalling, “They asked me if I wanted birth control. I wasn’t sure because I’d never had it. And then we talked about getting my tubes tied, and all the doctors said they wouldn’t do it unless we had another baby…actually, one of them said, well, you need to have one more child. I think we’re done [having kids]. And then the other one said he’d had bad experiences giving women sterilizations or whatever because they always regret it. So, he said that he wouldn’t do it unless I was at least 30… and now I’m pregnant.”

Strong Support Networks

Both rural only and closure community participants noted an unmet need for information and wished for greater connection to their community. Specifically, they desired community connections for ongoing support and information after delivery, especially after the delivery of their first child. One participant recalled, “I really feel like I wasn’t given very much information. I wasn’t really in control of anything. Things weren’t explained to me while I was in the office. Like even down to the testing that they did.” When asked whether one participant was involved in any support groups, they said, “you needed to already be in a [new mom] group before you were pregnant.” Another participant recalled, “I had to kind of ask about it or already have had friends that have been down that path. It wasn’t as easy to access as out as I had hoped.”

The type of support that the most participants “starred” (i.e., indicated was most impactful) was family and friends who were able to take care of home life while the participants delivered, stayed in the hospitals, and transitioned back home. In many cases, in-laws and parents were employed to watch the older children and family pets while the participant delivered. The five participants that identified familial support as a star support all resided in rural-only communities. Other delivery-related supports included having kids and partners

present during the delivery, and individuals with midwives and doulas were thankful for their experience, advocacy, and support during the delivery.

> "I loved that my midwife stayed with me through the entire C-section process. She was a really good advocate for me. I was having trouble when they were putting in the spinal block… and she was just really helpful getting me through that stuff like that. They should just make having a midwife or doula standard for the C-section. It was helpful."

Participants were also immensely thankful for their health and their healthy baby, and grateful to their care teams for knowledgeable and kind bedside manner and special moments like "jamming out to grateful dead with my doctor" during their cesarean delivery surgery and having delivery photos taken by their best friend and doula.

Inflection Points in the Maternity Care System

A number of topics were discussed by participants in very different ways - barriers by some and facilitators by others – showing how the topic has a strong potential to color the experience of maternity care. The inflection points in the maternity care system identified in this study include mental health supports, travel distance, provider relationships, and community integration (Table 5).

TABLE 5: LOGISTIC REGRESSION MODEL OUTPUT PRESENTED AS ODDS RATIOS. DEPENDENT VARIABLE IS THE PROBABILITY OF SEVERE MATERNAL MORBIDITY.

	Predictors			**Subset of Beneficiary-Level Predictors**		
	All Variables	Without Plan	Without Plan and Travel Time	All Variables	Without Plan	Without Plan and Travel Time
Race (White is Referent)						
Black	0.796*	0.917*	0.889*	0.783*	0.924*	0.907*
	(0.027)	(0.030)	(0.022)	(0.025)	(0.028)	(0.020)
American Indian/Alaskan Native	0.964	0.990	0.850+	0.858	0.921	0.847*
	(0.100)	(0.101)	(0.071)	(0.085)	(0.089)	(0.067)
Other	0.524*	0.573*	0.620*	0.541*	0.578*	0.625*
	(0.065)	(0.069)	(0.051)	(0.060)	(0.063)	(0.046)
RUCA Designation (Metropolitan Core is Referent)						

2. Metropolitan area high commuting	1.008	1.046	1.053	0.926	1.005	1.026
	(0.052)	(0.053)	(0.038)	(0.044)	(0.046)	(0.034)
3. Metropolitan area low commuting	1.008	1.097	1.024	0.849	0.990	0.980
	(0.134)	(0.143)	(0.105)	(0.108)	(0.123)	(0.096)
4. Micropolitan area core	1.086+	1.159*	1.088*	0.964	1.091*	1.039
	(0.053)	(0.055)	(0.039)	(0.042)	(0.046)	(0.033)
5. Micropolitan high commuting	1.076	1.121	1.032	0.943	1.046	0.983
	(0.086)	(0.088)	(0.061)	(0.071)	(0.077)	(0.054)
6. Micropolitan low commuting	0.954	1.049	1.158	0.867	1.021	1.083
	(0.161)	(0.173)	(0.107)	(0.136)	(0.156)	(0.094)
7. Small town core	0.939	1.041	1.037	0.818*	0.961	1.001
	(0.077)	(0.083)	(0.061)	(0.062)	(0.071)	(0.054)
8. Small town high commuting	0.819	0.837	0.852	0.791+	0.846	0.833
	(0.121)	(0.122)	(0.104)	(0.111)	(0.117)	(0.097)
9. Small town low commuting	0.991	1.013	1.019	0.803	0.870	0.952
	(0.185)	(0.185)	(0.131)	(0.141)	(0.149)	(0.112)
10. Rural areas	1.033	1.114	0.931	0.901	1.008	0.891+
	(0.084)	(0.088)	(0.063)	(0.068)	(0.074)	(0.056)
Member Age at Delivery (19 Years or Less Is Referent)						
20-24	1.100	1.059	1.010	1.089	1.006	0.972
	(0.075)	(0.067)	(0.044)	(0.072)	(0.062)	(0.041)
25-29	1.213*	1.175*	1.158*	1.242*	1.145*	1.124*
	(0.083)	(0.074)	(0.051)	(0.082)	(0.070)	(0.047)
30-34	1.367*	1.355*	1.310*	1.398*	1.305*	1.258*
	(0.099)	(0.091)	(0.062)	(0.097)	(0.085)	(0.057)
35-39	1.531*	1.578*	1.539*	1.693*	1.628*	1.537*
	(0.125)	(0.122)	(0.084)	(0.130)	(0.118)	(0.079)
>=40	5.662*	15.545*	12.927*	5.765*	16.408*	13.538*
	(0.401)	(0.955)	(0.562)	(0.395)	(0.980)	(0.566)
Travel Time to Delivery Location	1.001*	1.001*	-	1.001*	1.001*	-
	0.000	0.000	-	0.000	0.000	-
Days Discharged After Delivery	1.000	1.001*	1.001*	-	-	-
	0.000	0.000	0.000	-	-	-
Days of Prenatal Care Before Delivery	1.001*	1.002*	1.002*	-	-	-
	0.000	0.000	0.000	-	-	-
Number of OB/GYNs in County	1.158*	1.126*	1.045+	-	-	-

	(0.040)	(0.039)	(0.026)	-	-	-
Number of CNMs in County	0.725*	0.760*	1.043	-	-	-
	(0.056)	(0.058)	(0.053)	-	-	-
Social Vulnerability Index	0.722*	0.776*	0.892*	-	-	-
	(0.047)	(0.050)	(0.044)	-	-	-
High Risk Pregnancy	1.636*	1.595*	1.285*	-	-	-
	(0.076)	(0.072)	(0.051)	-	-	-
Type of Medicaid Coverage (Work First Family Assistance is referent)						
Medicaid to the Disabled	2.041*	-	-	2.297*	-	-
	(0.282)	-	-	(0.315)	-	-
Medicaid to Families with Dependent Children	0.383*	-	-	0.404*	-	-
	(0.051)	-	-	(0.054)	-	-
Medicaid to Infants and Children	0.429*	-	-	0.445*	-	-
	(0.076)	-	-	(0.078)	-	-
Medicaid to Pregnant Women	0.357*	-	-	0.384*	-	-
	(0.048)	-	-	(0.051)	-	-
Other	4.151*	-	-	4.901*	-	-
	(0.600)	-	-	(0.701)	-	-
Constant	0.020*	0.006*	0.008*	0.023*	0.010*	0.013*
	(0.003)	0.000	0.000	(0.003)	(0.001)	0.000
N	319567	319567	508478	347008	347008	556205

Discussion

Findings from this study revealed some tensions between the services and supports women desired and potentially necessary rural maternity care system functions and/or existing policies. For example, since rural hospitals often have low birth volume and a minimum number of deliveries are required for provider certification, multiple providers and support staff may need to be involved in a birth. However, patients preferred to have a few consistent providers and time alone after their delivery – "you're looking at family medicine residents, OB-GYN residents, there's just a lot of people coming in and out of your room and… the continuity of care is non-existent." Some of the comments about the strictness of laboring (i.e., whether the patient

could walk around or use a birthing ball) may also reasonably be because deliveries do not happen often, and the situation is novel or uncomfortable for the provider and care team. Similarly, limiting care to six weeks postpartum is consistent with many insurances coverage plans, but participants did not feel comfortable with the policy and wanted additional visits throughout the postpartum period. Finally, participants sent home 24 hours after delivery felt it was dangerous and put them at risk of complication or hemorrhage.

For some participants, specific practice policies influenced participant decisions about where and when they would receive care and influenced their overall emotional experiences. Some obstetrics offices limited whether children were allowed to join their mothers for visits, which impacted the frequency of visits as well as the distance traveled to appointments. One participant drove a "45-minute commute every week, just to see a doctor that would allow my child to go." Similarly, another participant had a positive experience with their provider, noting, "Well, they let me bring my daughter to all my appointments. I mean, if they didn't let me do that…I don't know how I would've made it." Policies around eating during labor and having children in the room while delivering were also sources of conflict for the participants. Involvement in maternity care from other immediate family members was seen as an opportunity to develop strong bonds and connection as the family prepared, welcomed, and transitioned home with their newborn.

Some women also expressed a level of comfort knowing a hospital was close, even if that hospital does not have a designated maternity care unit. One participant described, "I felt comfortable personally taking on that risk to deliver at home because we are maybe 12 minutes, 10 minutes from if you dress fast, from the hospital. I felt comfortable in that the resources I would need postpartum… I could access at that hospital, although they don't do babies." This

sentiment is significant and because though the patients feel confident, evidence shows emergency room providers are not always prepared to handle non-routine obstetrical emergencies (23, 24).

Findings revealed that the primary effect of rural maternity unit closures appeared to be an increase in travel times. Many of the other challenges and supports identified by participants were the same across communities and were tied to insurance and provider or facility policies. Potentially due to the scheduled nature of maternity care, the closure of local units may have less effect on whether a service is received at all, as a binary measure, but instead affect the level of burden the individual experiences while trying to receive care. In many cases, emergency rooms are unprepared or uncomfortable handling maternity care cases, highlighting a discrepancy between patient perception and the reality of care available in the community to handle birth complications (25, 26). These findings reinforce messages from organizations, like Alliance for Innovation on Maternal Health (AIM) and Institute for Perinatal Quality Improvement, pushing for obstetric readiness simulations and training across a range of emergency department providers.

Findings from this study are similar and consistent with previous research. For example, two studies specific to North Carolina found hospital-based maternity unit closure disproportionately affected women on Medicaid and increased travel time to hospitals (27) and the closure of maternal units caused frustration across the entire Appalachian community, and led to distrust of medical institutions among some participants (20). Similarly, a study from 2005 found in the wake of hospital obstetric unit closures across Canada, rural maternity care lacked robust infrastructure which created unsafe delivery conditions, tensions within the healthcare system and amongst providers, and care that is "dependent on the vagaries of

individual providers (18).” Finally, a systematic review of qualitative studies across England, Australia, Canada, and Scotland found that maternal health challenges in rural communities include lack of access, care coordination, making informed choices, and high travel costs for patients (28). Inflection points identified in this study offer potential opportunities to improve the maternity care system experience across rural North Carolina but especially in communities at risk or after maternity unit closure.

Limitations

First, the sample size for rural only and closure community subgroups is limited, so results should be interpreted with caution and may not represent the sentiments or feelings of all women in these respective groups. Factors contributing to the low sample size are primarily the result of the current public health emergency. Recruitment relied heavily on health care providers and organizations who were responding to the emergency. Many maternity care visits were virtual and waiting room times were limited, reducing the number of people exposed to recruitment materials. The recruitment methods also relied on convenience sampling, which can bias results toward extremes. Participants with especially negative or positive experiences may be more likely to seek participation in the study.

Further, since the study included deliveries between 2011 and 2019, many potential participants had children at home as daycare and schools were closed for part of the data collection period because of the COVID-19 public health emergency. Many potential participants expressed interest in the study but were too overwhelmed to participate. All participants were not from the same rural communities. As a result of an effort to have voices from across North Carolina, this tradeoff came at the cost of having individuals with more similar external environment and starting conditions among which to compare answers.

Interviews and coding were conducted and analyzed by one individual, which affects the objectivity of the analyses. Bypass behavior, or intentionally passing one's closest facility for another place of service, was not considered when establishing hospital markets, and, to address this concern, individuals were asked to confirm their assigned group at the beginning of the interview.

A more structured mapping format (e.g., enforcing rules on the number of sticky notes allowed per circle, drop downs, lists to choose from, etc.) would have provided more uniform maps, and information could be more consistently coded and synthesized. However, the approach used in this study allowed participants to think about their pregnancy journey with an anchor other than across time. By anchoring experiences to places and forcing connections across places and to events and experiences, participants discussed how the presence or absence of a place impacted their maternity care. Allowing participants to dictate the number of sticky notes and connections explored more facets of their experience and yielded richer data than imposing restrictions in a more structed mapping approach. In the future, having standard responses or phrases that can be applied to a sticky during the interview with verification from the participant could help minimize the subjectivity applied in the code reduction process.

Relationship to Other Aims

In addition to understanding how maternity unit closures affect the provision of rural maternity care, this paper was conceptualized as a hypothesis-generating exercise to inform subsequent analyses. As part one of a three-part study, future papers will explore items and themes identified in this paper in administrative claims data. Based on the findings of this paper, the following variables will be considered for inclusion in Aim 2, which focuses on the impact of service provision and frequency of services received on maternal health outcomes (Table 6).

TABLE 6: LIST OF VARIABLES FOR CONSIDERATION IN SUBSEQUENT QUANTITATIVE AIMS DERIVED FROM FINDINGS IN THIS PAPER.

Paper Finding	Proposed Variable	Purpose
Transportation Availability; Community Integration	Social Vulnerability Index	Describe the community in which the individual lives, including community demographics and social supports in the community
Remoteness	Rurality (measured via FORHP definition for consistency)	Measure of physical isolation
Distance to providers for prenatal, postpartum, and delivery services	Geocoded driving travel time	Travel Burden
Distance to providers via public transportation	Geocoded public transportation travel time	Travel Burden
Nearest Emergency Room	Geocoded driving time to nearest emergency room	Emergency care access
Postpartum Emergency Room visit	Hospital claims after delivery; whether the same hospital as delivery was visited	Postpartum complications; Care continuity and obstetric readiness
Type of Medicaid Coverage	Beneficiary Plan	Insurance restrictions
Mental Health Supports	Referral to Enhanced Mental Health and Substance Abuse Services; Medicaid screening code	Addressed mental health concerns; received screening
Initiation of prenatal services	Number of weeks between first prenatal appointment and delivery	Indication of risk assessment
Receipt of postpartum services	Six-month appointment; number of weeks between follow-up appointment and delivery	Received follow-up care; receive follow-up care within recommended window
Maternity-adjacent services	Other appointments in claims	Other provider-related touchpoints during prenatal or postpartum
Breastfeeding Support	Referral to lactation services via Medicaid	Other maternity care touchpoint
Caesarean sections, observation after surgery	Delivery Type; Discharge Date	Indication of potential complications; time under observation before sent home

Implications for policy and future research

Although we were not able to measure outcomes in this study, the implications of additional burden on rural women, especially those who experience maternity care unit closures could lead to long term impacts that affect child development and the health of the mother. Research shows the psychological state of the mother during pregnancy influences fetal

neurobehavioral development as well as affects whether the baby is born premature or underweight. Mothers who experience significant distress during pregnancy may develop high blood pressure which is linked to preeclampsia (29, 30). Preeclampsia is one of the risk factors for postpartum hemorrhage, a primary cause of maternal mortality (31). Preeclampsia also increases the woman's risk for diabetes, heart disease, and kidney disease over her lifetime (32). Future research exploring these potential pathways to maternal morbidity and mortality, as well as future chronic conditions, is necessary to understand possible drivers of rural and urban maternal health disparities.

Further research is needed to understand how women access care in rural communities and how the closure of obstetrics units affects utilization and subsequent outcomes for the mother and baby. Specifically, future research with sufficient power to identify potential differences by race, level of remoteness, and primary insurance provider is needed to understand challenges and supports for system improvement. Interaction effects between these variables and rural maternity unit closures also appear to be important but are understudied. Findings from this study suggest rural women who deliver after a maternity unit closure in their community face additional burden and stress accessing care.

AIM 2: PATIENT AND COMMUNITY FACTORS ARE STRONG PREDICTORS OF SEVERE MATERNAL MORBIDITY AMONG NORTH CAROLINA MEDICAID BENEFICIARIES

Background

Despite spending the highest percentage of gross domestic product on health care compared to other industrialized nations, the United States has the highest maternal mortality rate (17.4 per 100,000 live births), double the rate of the second-place large, wealthy peer country (33). Severe maternal morbidity, which the U.S. Centers for Disease Control and Prevention defines as "unexpected outcomes of labor and delivery that result in significant short- or long-term consequences to a woman's health," has increased 200% in the U.S. between 1993 and 2014 (34). One severe maternal morbidity measure, blood transfusion rates during childbirth, also occurs more frequently in the U.S. than in peer European nations (33). The amassing amount of evidence of a maternal mortality and morbidity crisis in the U.S. begs the question – Why are rates increasing in the United States?

Clinical factors, like preexisting conditions (e.g., diabetes, hypertension, anemia, heart disease, etc.), delivery via cesarean section, and infections have been shown to play a role, but these factors alone do not explain the increase in cases over the past twenty years (35, 36). Differences in maternal health outcomes between white people and Black and American Indian/Alaskan Native people have been linked to the communities in which the people live, particularly communities affected by historical and ongoing discrimination and racism. Black women who live in communities with high violent crime and air pollution have the highest risk of preterm birth (37). Women in rural communities have higher maternal mortality rates than

their urban peers and 45% of rural counties do not have an obstetric provider – a number increasing as rural hospital-based obstetrics units continue to close across the country (38, 39). Despite existing knowledge of clinical factors and racial disparities, high maternal morbidity rates persist. Several Federal and State-level initiatives have been introduced to target poor maternal health outcomes, and implementation of plans and programs will be more successful if high-need communities are recipients of these efforts (40).

Thus far, researchers have used traditional econometric methods and theory-based analyses to identify important factors related to maternal health outcomes. In contrast, supervised machine learning models offer a unique opportunity to identify key predictors of maternal mortality without the need to build out a specified model and theorize relationships (41). Machine learning models develop predictions from input data and identify patterns that may be unknown to the modeler rather than test prespecified hypotheses. Machine learning models are able to take lengthy variable lists and identify which combination of variables are able to best predict a binary outcome variable, test thresholds within variables that help discriminate between outcome states, and are not beholden to model assumptions or linear variable relationships required in tradition econometric models. In this study, we use a broad range of indicators derived from Medicaid beneficiary demographic data, the community in which the beneficiary lives, and clinical factors from the beneficiary's medical claims files in machine learning models to identify key predictive factors of severe maternal morbidity. This study adds to existing literature by combining previously identified predictors of maternal morbidity into a single study to examine the relative importance of factors driving poor maternal outcomes.

Methods

Variable Descriptions

Patient-level maternity care data was compiled from North Carolina Medicaid claims and included all deliveries that occurred between January 1st, 2016 to December 31st, 2019. For each identified delivery, professional and institutional claims for each beneficiary were pulled one year before and one year after the delivery date to construct a dataset with all maternity care visits billed to Medicaid throughout the pregnancy, delivery, and postpartum periods. Care profiles for each beneficiary-delivery date combination were created using the presence of maternity-related codes in the beneficiary's professional and institutional claims files (See Table 7 variable descriptions). Clinical indicators were created from patient-level Medicaid claims data according to NC Medicaid obstetric care manuals and International Classification of Diseases (ICD) 9 and 10 lists of diagnosis and procedure codes. Clinical variables included indicators for high-risk pregnancy, cesarean or vaginal delivery, a prenatal care visit, prenatal care intensity, a postpartum visit, preterm delivery, the same provider for all prenatal, delivery, and postpartum encounters, part of a Pregnancy Medical Home, referral to other Medicaid programs, emergency room visit before or after delivery, the number of days the patient was in the hospital after delivery before they were discharged, the number of days between the initiation of prenatal care and delivery, and pregnancy-related complications from pre-eclampsia, substance abuse, sexually transmitted diseases, smoking, diabetes, obesity, hypertension, anemia, abuse, and prolonged delivery or exhaustion. Given the time span of analysis, all IDC codes specific to ICD 9 or 10 were matched to their counterpart, when possible, using IDC code manuals from the Centers for Medicare & Medicaid Services website.

TABLE 7: LISTS OF VARIABLES, SOURCES, AND DESCRIPTION OF HOW EACH VARIABLE IS CONSTRUCTED.

Variable	Source	Construction
Clinical Variables		
Variable	Source	Construction
Severe Maternal Morbidity	Division of Reproductive Health, National Center for Chronic Disease Prevention and Health Promotion	Binary; All diagnosis codes (21 indicators) for Severe Maternal Morbidity according to the Severe Morbidity Indicators and Corresponding ICD-9-CM/ICD-10-CM/PCS Codes during Delivery Hospitalizations
High Risk Pregnancy	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; Diagnosis Codes that Substantiate High-Risk Deliveries for Maternal Stand-by Service
Vaginal Delivery	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; All DRG and CPT codes that indicate vaginal delivery
Cesarean Delivery	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; All DRG and CPT codes that indicate cesarean delivery
Complications from pre-eclampsia during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from substance use during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from sexually transmitted diseases during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from smoking during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from diabetes during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from obesity during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from hypertension during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from anemia during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from abuse at home during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual

Complications from HIV during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Prenatal care initiation	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5, ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Individual and global codes that indicate a prenatal event occurred
Prenatal care intensity	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; Code for 4-6 Visits, Code for 7+ Visits
Postpartum visit	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5, ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Individual and global codes that indicate a postpartum event occurred
Delivery Complications related to exhaustion	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Preterm Delivery	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Same provider for all prenatal, delivery, and postpartum encounters	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; Global code billed by provider that indicates all services provided
Referred to other Medicaid programs for pregnant women	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Codes for referral to Dietary Evaluation and Counseling and Medical Lactation Services, Enhanced Mental Health and Substance Abuse Services, and Health and Behavior Intervention Services
Included in a Pregnancy Medical Home	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-6	Binary; Referral codes and codes billed by Pregnancy Medical Home
Emergency Department Visits	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Revenue code for Emergency Room with before and after delivery date indicator
Days Before Discharge After Delivery	Claim Service Dates	Continuous; Number of days after delivery patient was discharged
Location of Delivery	Taxonomy of Billing Provider	Categorical; Derived from billing provider taxonomy
Member Variables		
Variable	Source	Construction
Age at time of delivery	Medicaid member file	Continuous; Derived from member birthdate and day of delivery; Restricted to ages 12-55 based on criteria from CDC severe maternal morbidity guidance. In categorical representations, age was converted into one of the following categories: ≤ 19, 20–24, 25–29, 30–34, 35–39, and ≥ 40

Race	Medicaid member file	Categorical; Race collapsed to identify all individuals who identified as White, Black, Native American/Alaskan Native, or other remaining categories. If any of the race variable indicated Black or Native American, the member was included in those categories.
RUCA Designation	Medicaid member file; 2010 Rural-Urban Commuting Area (RUCA) Codes Economic Research Service U.S. Department of Agriculture	Categorical; Member zip codes matched to RUCA zip (level one RUCA code only)
Ethnicity	Medicaid member file	Binary; Ethnicity collapsed to indicate Hispanic ethnicity if any ethnicity is selected
Travel Time to Delivery Location	Medicaid member file; NPI files with Zip code of Delivery Billing Provider	Continuous; Geocoded residence zip code centroid to delivery zip code centroid from NPI file
Living Arrangement	Medicaid member file	Categorical; Collapsed to private living arrangement and other
Medicaid Coverage Type	Medicaid member file	Categorical; Collapsed to Medicaid to the Disabled, Medicaid to Families with Dependent Children, Medicaid to Infants and Children, Medicaid to Pregnant Women, and Other
Community Variables		
Variable	Source	Construction
Number of Obstetricians and Gynecologists in county per 10,000 population	North Carolina Health Professions Data System, Program on Health Workforce Research and Policy, Cecil G. Sheps Center for Health Services Research, University of North Carolina at Chapel Hill	Continuous; County-level rates matched to member county; Data years matched to delivery years
Number of Certified Nurse Midwives in county per 10,000 population	North Carolina Health Professions Data System, Program on Health Workforce Research and Policy, Cecil G. Sheps Center for Health Services Research, University of North Carolina at Chapel Hill	Continuous; County-level rates matched to member county, Data years matched to delivery years; 2011 and 2012 data unavailable and replaced with 2013 data
Closure Community	Medicaid member file; NPI files with Zip code of Delivery Billing Provider, Closure List	Categorical; collection of zip codes based on pre-closure market area and further restricted to a 30-mile radius
Social Vulnerability Index	Medicaid member file; CDC/ATSDR Social Vulnerability Index North Carolina Overall SVI Ranking by zip code	Continuous; Delivery Years 2011-2014 matched at county level to 2014 SVI, 2015-2016 matched to 2016 SVI, all other years matched to 2018 SVI

Number of months delivering after local maternity unit closure	Medicaid member file; Maternity Unit Closure List (Appendix 4)	Continuous; Calculated months between closure month and year and delivery month and year

Patient-level information, including patient zip code, age at delivery, ethnicity, and race, living arrangement and Medicaid coverage type was extracted from the Medicaid beneficiary file for the month of the individual's delivery. Using beneficiary zip code information from the member enrollment file, rural-urban commuting area (RUCA) designation (42) and travel time between the zip code centroid of the patient and delivery location was assigned. Other variables merged by beneficiary county or zip code at the time of delivery were sourced from publicly available datasets. These variables included the number of Obstetricians and Gynecologists in the county (OB/GYNs), the number of Certified Nurse Midwives (CNMs) in the county, and the Social Vulnerability Index ranking for each zip code. Indicators for closure communities are defined by two factors. First, for each hospital or hospital-based maternity unit that closed during the study period, a list of beneficiary zip codes for people that delivered at the hospital in the period prior to the closure was compiled using the delivery billing National Provider Identifier (NPI). Second, a list of zip codes within 30 minutes of driving from the zip code of the hospital was created. Residents with delivery zip codes meeting both of these two criteria and with delivery dates after the month and year of the maternity unit closure were flagged as closure community deliveries.

Analysis

The most popular models for supervised machine learning classification problems are random forest algorithms. In short, random forest algorithms grow parallel "trees" based on model specifications like tree depth, the number of splits allowed at each node, and the number of trees grown, and use information from each tree in a voting process to determine an

ensembled tree model (See Table 8 for definitions) (41, 43). For the purposes of this paper, we are most concerned with the variable importance calculation which ranks variables by Gini index – the reduction of impurity of the outcome variable given by the knowledge from informative and uninformative variables (44). This measure of decrease in impurity is not affected by tuning the aforementioned model specifications (45). Higher ranked variables using Gini index impurity as a measure of importance mean these variables are the best at separating the model into each class, which we inferred to be highly predictive of the outcome group. In this paper, classes represent the two outcome states (also referred to as classification or outcome groups) – the minority class, deliveries with a severe maternal morbidity outcome indicator, and the majority class, deliveries without a severe maternal morbidity outcome indicator.

TABLE 8: RANDOM FOREST MODEL TERMS AND DEFINITIONS.

Term	Definition
Trees	Individual decision tree
Number of Trees	Number of decisions trees in the forest. Standard to use ten times the number of variables as minimum number of trees.
Minimum Node Size	The minimum number of observations in a terminal node. Ranger default for probability trees is 10 (i.e., 10 observations must be in each terminal node in each tree)
Maximum Tree Depth	Ranger default is unlimited. Restricted by the minimum node size.
Random Forest	Ensemble of decision trees. Final model used for predictions in test dataset.
Accuracy	(TP+TN)/(TP+TN+FP+FN)
True Positive Rate (Sensitivity)	TP/(FN+TP)
True Negative Rate (Specificity)	TN/(TN+FP)
False Positive Rate	FP/(FP+TN)
False Negative Rate	FN/(FN+TP)

Note: TN, True Negatives; TP, True Positives, FP, False Positives; FN, False Negatives

In the random forest models, continuous variables were each binned into quintiles of equal observations and a sixth category for missing observations. In cases where quintile values were duplicates, quantile bins were created instead. Binary and categorical variables retained their order and were assigned a separate category for missing observations. Assignment of missing categories retains patient observations with missing values in one or more variable in analysis. Prior to sampling, the dataset was divided into test and training datasets. Eighty percent of the dataset was randomly assigned and designated as the training dataset used to develop the model. The remaining 20% of the data was assigned a prediction value from the model. Model performance was assessed using a confusion matrix to calculate the specificity, sensitivity, and accuracy of the model using the test set predictions and actual outcomes. Analyses were performed in R using the Ranger package (46). Since variable importance rankings do not change with additional model tuning, Ranger package defaults were used in analysis.

Severe maternal morbidity is a rare event associated with about 2% of all pregnancies in the United States (47). To accommodate this, sampling methods and model specifications were selected according to recommendations developed for models with rare event outcomes, also referred to as imbalanced classification models (48, 49). In one model, the under-sampled model, the majority class was under-sampled to create a balanced sample of observations in the majority and minority classes – in our case, people who did (minority) and did not (majority) experience a severe maternal morbidity event. To achieve a balanced sample, all minority observations are sampled, and majority class observations are randomly sampled without replacement until the number of observations match the number of minority observations. This approach is favored to using an imbalanced sample because random forest models can achieve highly accurate models by only predicting the majority class.

In a class-weighted model, we used the complete set of observations in the training subset (the randomly assigned 80% of the full dataset) but imposed class weights to penalize the model for incorrectly classifying the minority class. To achieve balance through class weights, each class was inversely weighted, where the majority class was weighted by the prevalence of minority cases and vice versa. In the Ranger package implementation of class weights on the outcome, class weights force cost-sensitive learning (i.e., the cost of prediction error) and are also used in voting processes to determine the final model.

Severe Maternal Morbidity Model

Key predictor variables of severe maternal morbidity in the random forest model were used to estimate the predicted probability of a severe maternal morbidity event through logistic regression models. A logistic regression model with the top predictor variables was used to estimate the impact of factors across multiple socio-ecological levels in the maternity care system on maternal morbidity, and a second logit model with only the beneficiary-derived variables was used to assess the effect of beneficiary-derived factors on severe maternal morbidity. Finally, the predicted probability of severe maternal morbidity at various travel times was calculated using the beneficiary-derived variable model.

Results

Random Forest Model

Table 9 includes counts of each variable used as potential predictors in each of the models pooled over the study period (2016-2019). Ten variables included in Table 9 were ultimately excluded from the models due to extremely small case size or unreliable values (less than 10 cases over nine years) in the minority class: emergency room visit before delivery, emergency room visit after delivery, indication of prenatal lab services, preterm delivery,

prenatal care intensity (4-6 and 7 or more visits), number of days between postpartum visit and delivery, referral to a dietary program, referral to a lactation program, referral to enhanced mental health and substance abuse services, and referral to a health behavior intervention. Indicators of prolonged delivery and abuse were excluded from Table 9 and models to meet data suppression requirements. Of the deliveries with non-missing values for severe maternal morbidity (N=248,678), severe maternal morbidity occurred in 0.99% of deliveries. Deliveries with severe maternal morbidity were more prevalent for women who delivered at older ages (31 versus 27), had pregnancies flagged as high-risk pregnancies, traveled farther to the delivery location (mean of 6.4 additional minutes), delivered via cesarean section, initiated prenatal care earlier in pregnancy, and had pregnancy complications due to substance use, smoking, hypertension, anemia, HIV, abuse, or pre-eclampsia. Severe maternal morbidity cases also had a higher percentage of people with a postpartum visit and fewer beneficiaries in pregnancy medical homes.

The undersampled random forest model outperformed the class-weighted model as the class-weighted did not predict classification as well – visible in comparison of Figures 6 and 7 is the amount of overlap between the two classes indicating the model is poorly predicting outcome classification.

TABLE 9: TABLE OF CASES BY VARIABLE AND SEVERE MATERNAL MORBIDITY EVENTS.

Predictor Variable	Deliveries Without Severe Maternal Morbidity		Deliveries With Severe Maternal Morbidity		P-Value	Missing
Total Deliveries	N=248,678		N=2,478			
Member Age at Delivery	26.658	5.957	31.161	10.218	<0.001	3482
Member Living Arrangement						
Private Living Arrangement	247235	99.70%	2211	90.70%	<0.001	639
Other	790	0.30%	227	9.30%		
High Risk Indicator	34332	13.80%	856	34.50%	<0.001	0
Member Race						
White	150143	60.40%	1395	56.30%	<0.001	0
Black	87850	35.30%	975	39.30%		
Native American/Alaskan Indian	5040	2.00%	57	2.30%		
Other	5645	2.30%	51	2.10%		
RUCA Designation						
1. Metropolitan area core	144094	60.70%	1246	55.70%	<0.001	11546
2. Metropolitan area high commuting	27688	11.70%	268	12.00%		
3. Metropolitan area low commuting	2899	1.20%	30	1.30%		
4. Micropolitan area core	30147	12.70%	363	16.20%		
5. Micropolitan high commuting	9477	4.00%	98	4.40%		
6. Micropolitan low commuting	3041	1.30%	28	1.30%		
7. Small town core	8909	3.80%	81	3.60%		
8. Small town high commuting	2232	0.90%	18	0.80%		
9. Small town low commuting	1903	0.80%	20	0.90%		
10. Rural areas	6985	2.90%	83	3.70%		
Hispanic	51039	20.50%	259	10.50%	<0.001	0
Travel Time to Delivery Location	28.775	40.981	35.184	70.648	<0.001	53565
Social Vulnerability Index	0.476	25.89%	0.496	26.41%	<0.001	12006
Vaginal Delivery	180054	72.60%	1460	59.40%	<0.001	673
Cesarean Delivery	67973	27.40%	996	40.60%	<0.001	673
Part of Pregnancy Medical Home	61328	24.70%	175	7.10%	<0.001	0
Same Provider for All Encounters	5204	2.10%	36	1.50%	0.027	0
Prenatal Visit Indicator	225009	90.50%	2176	87.80%	<0.001	0
Postpartum Visit Indicator	159803	64.30%	1916	77.30%	<0.001	0
Smoking Indicator	18504	7.40%	83	3.30%	<0.001	0
Substance Use Indicator	10531	4.20%	124	5.00%	0.059	0
Obesity Indicator	27323	11.00%	155	6.30%	<0.001	0
STD Indicator	5270	2.10%	26	1.00%	<0.001	0
Diabetes indicator	16289	6.60%	79	3.20%	<0.001	0
Hypertension indicator	7410	3.00%	97	3.90%	0.007	0
Anemia Indicator	5582	2.20%	39	1.60%	0.025	0
HIV indicator	6,387	1.10%	327	3.10%	<0.001	0
Pre-Eclampsia Indicator	8058	3.20%	169	6.80%	<0.001	0
Days of Prenatal Care Before Delivery	192.111	90.935	241.431	112.301	<0.001	32,215
Delivery at Hospital	244597	98.40%	2414	97.40%	0.001	0

Delivery at Critical Access Hospital	3414	1.40%	38	1.50%	0.49	0
Number of OB/GYNs in County	1.042	61.12%	1.025	62.75%	0.20	12,006
Number of CNMs in County	0.273	23.28%	0.278	24.97%	0.37	12,006
Delivery Months After Closure	25.285	14.882	23.563	15.081	0.005	186,531
Closure Community Type	55768	58.80%	525	57.40%		
Hospital with Maternity Unit	38996	41.20%	390	42.60%	0.37	155,477
Maternity Unit	7.741	40.45%	11.516	35.92%		
Days Discharged After Delivery	1.042	61.12%	1.025	62.75%	<0.001	1114
Member Plan Type						
Medicaid to the Disabled	7208	2.90%	717	28.90%	<0.001	693
Medicaid to Families with Dependent Children	153458	61.70%	895	36.10%		
Medicaid to Infants and Children	3728	1.50%	28	1.10%		
Medicaid to Pregnant Women	82230	33.10%	356	14.40%		
Other	2054	0.80%	482	1.95%		

Note: Data are presented as mean (SD) for continuous measures, and n (%) for categorical measures.
(* p<0.05, ** p<0.01, *** p<0.001)

FIGURE 6: HISTOGRAM OF PREDICTED PROBABILITY OF SEVERE MATERNAL MORBIDITY FOR THE UNDERSAMPLED MODEL. COLORS REPRESENT THE ACTUAL INCIDENCE OF SEVERE MATERNAL MORBIDITY IN THE TEST DATA.

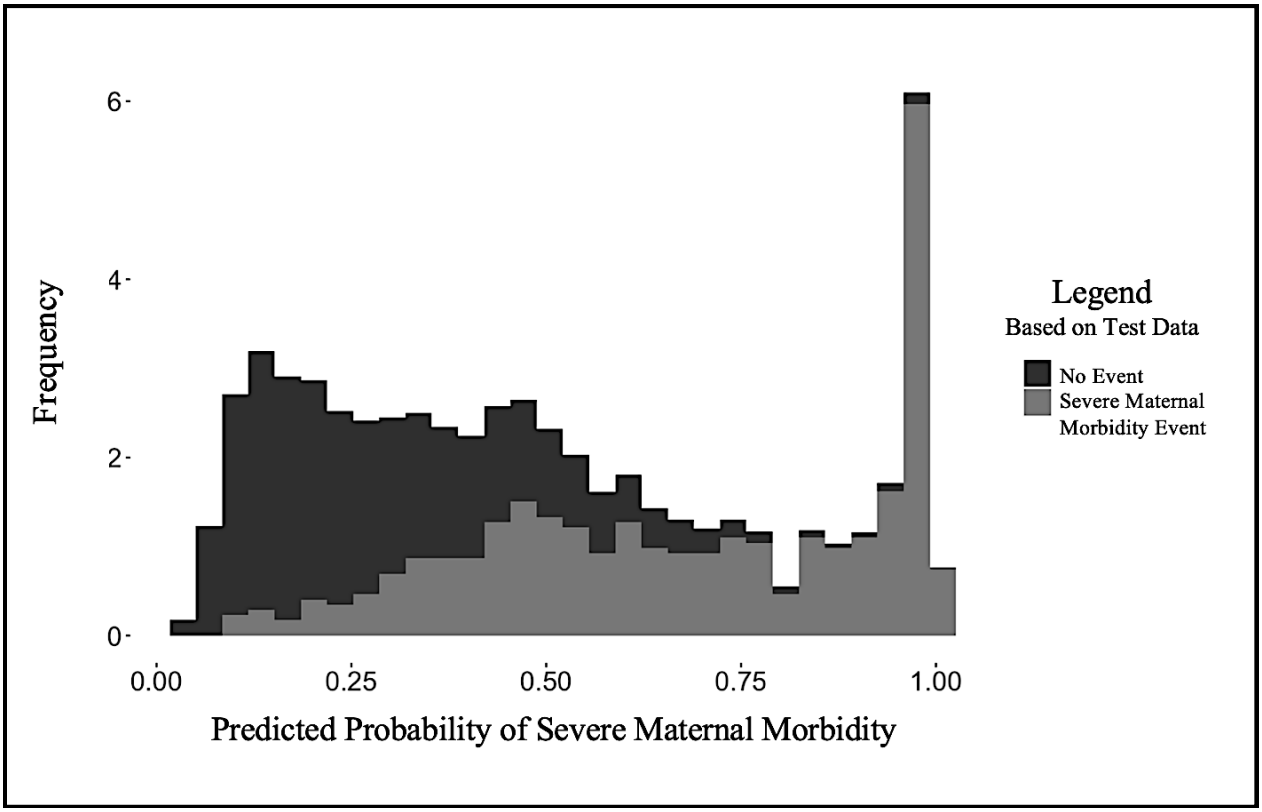
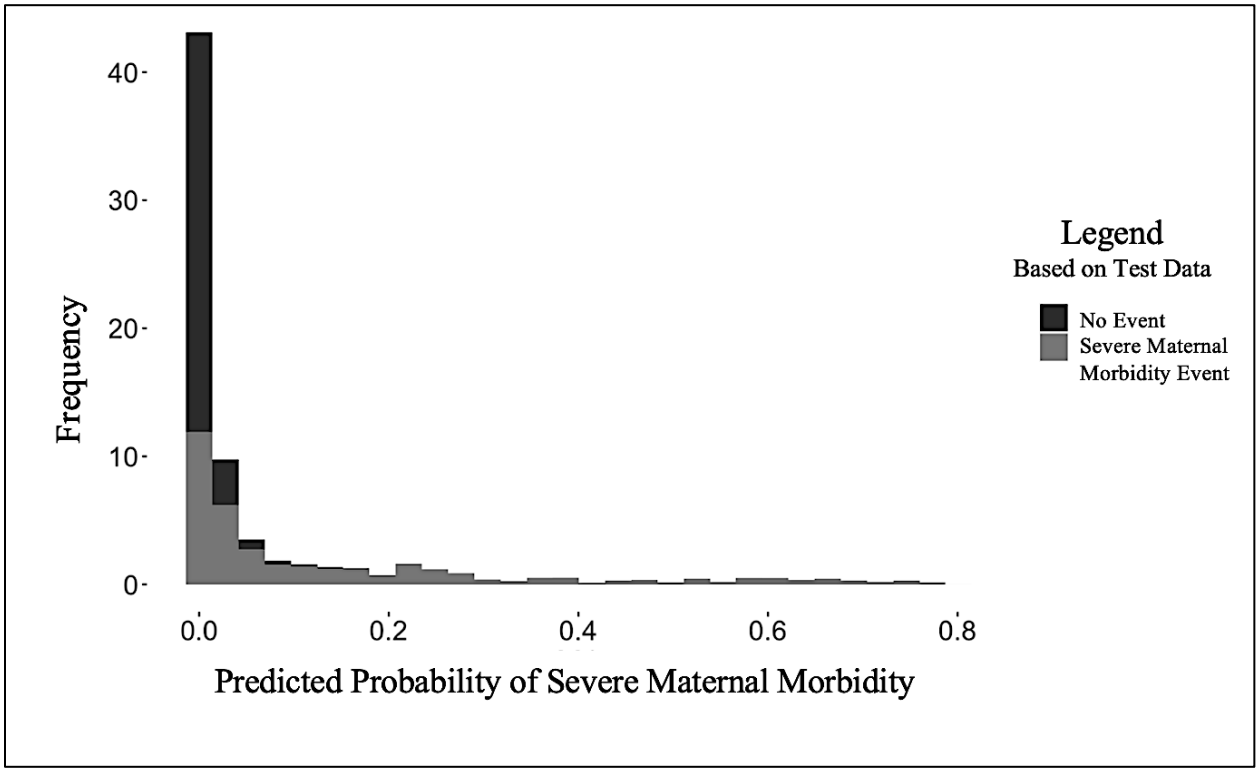


FIGURE 7: HISTOGRAM OF PREDICTED PROBABILITY OF SEVERE MATERNAL MORBIDITY FOR THE CLASS WEIGHTED MODEL. COLORS REPRESENT THE ACTUAL INCIDENCE OF SEVERE MATERNAL MORBIDITY IN THE TEST DATA.

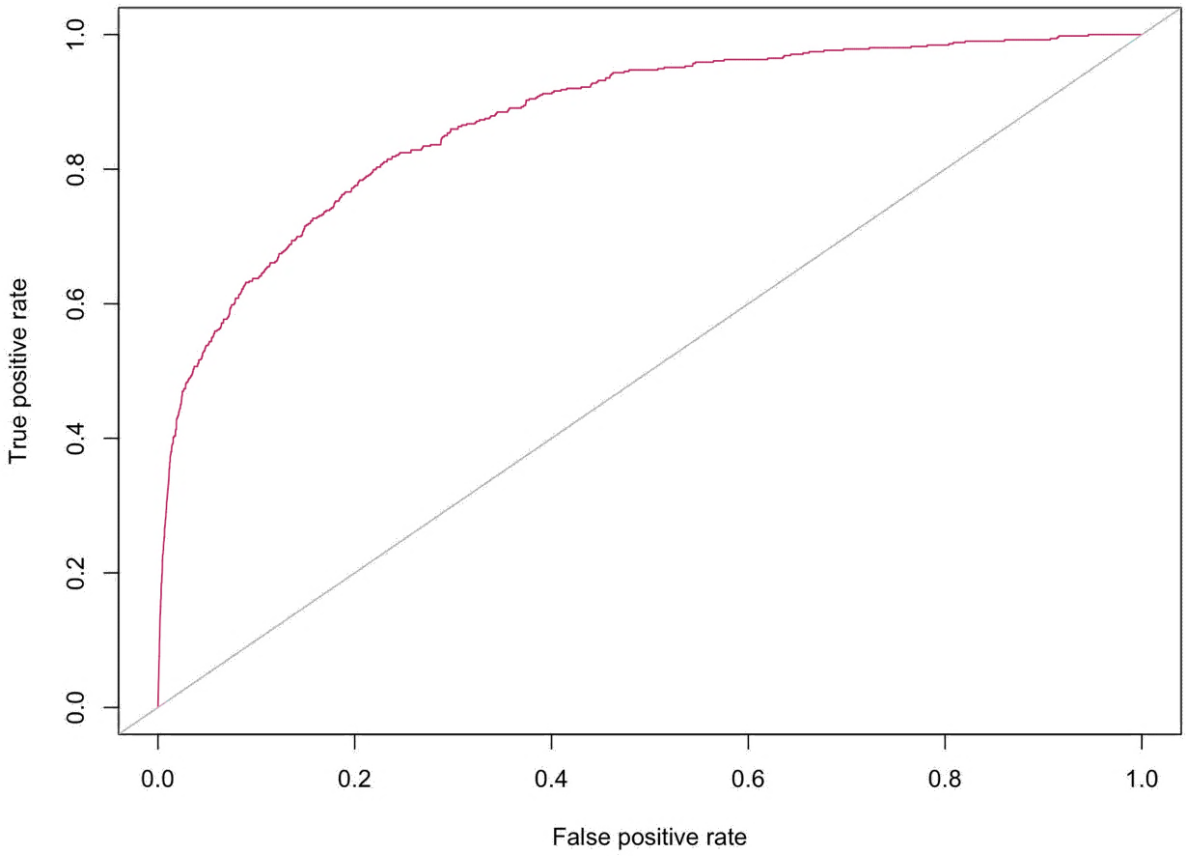


Model accuracy without tuning model specifications (i.e., using package defaults with classification threshold of 0.5) was 84.5% (95% Confidence Interval: 0.8421, 0.8485) (Table 10). Observations in the test subset of data were assigned a probability of classification as a severe maternity morbidity case using the random forest model. The receiver operating characteristic (ROC) curve in Figure 8 details the trade-off between the true-positive rate (sensitivity) and false-positive rate (1-specificity) of each classification threshold. The 45-degree line in the figure is the performance of a random classifier. The classification threshold that weighs sensitivity and specificity equally is 0.443 (sensitivity 0.799, specificity 0.781). In a scenario where we are more concerned with false negatives than false positives and the cost of false negatives is weighted 2X, the optimal classification threshold is 0.977.

TABLE 10: MODEL PERFORMANCE MEASURES FOR THE PREFERRED (UNDERWEIGHTED) MODEL.

Confusion Matrix Output			
		Actual	
		0	1
Prediction	0	42092	144
	1	7627	369
Accuracy			0.845
No Information Rate			0.989
Sensitivity			0.719
Specificity			0.847
Positive Predictive Value			0.046
Negative Predictive Value			0.997
Prevalence			0.010
Detection Rate			0.007
Detection Prevalence			0.159
Balanced Accuracy			0.783

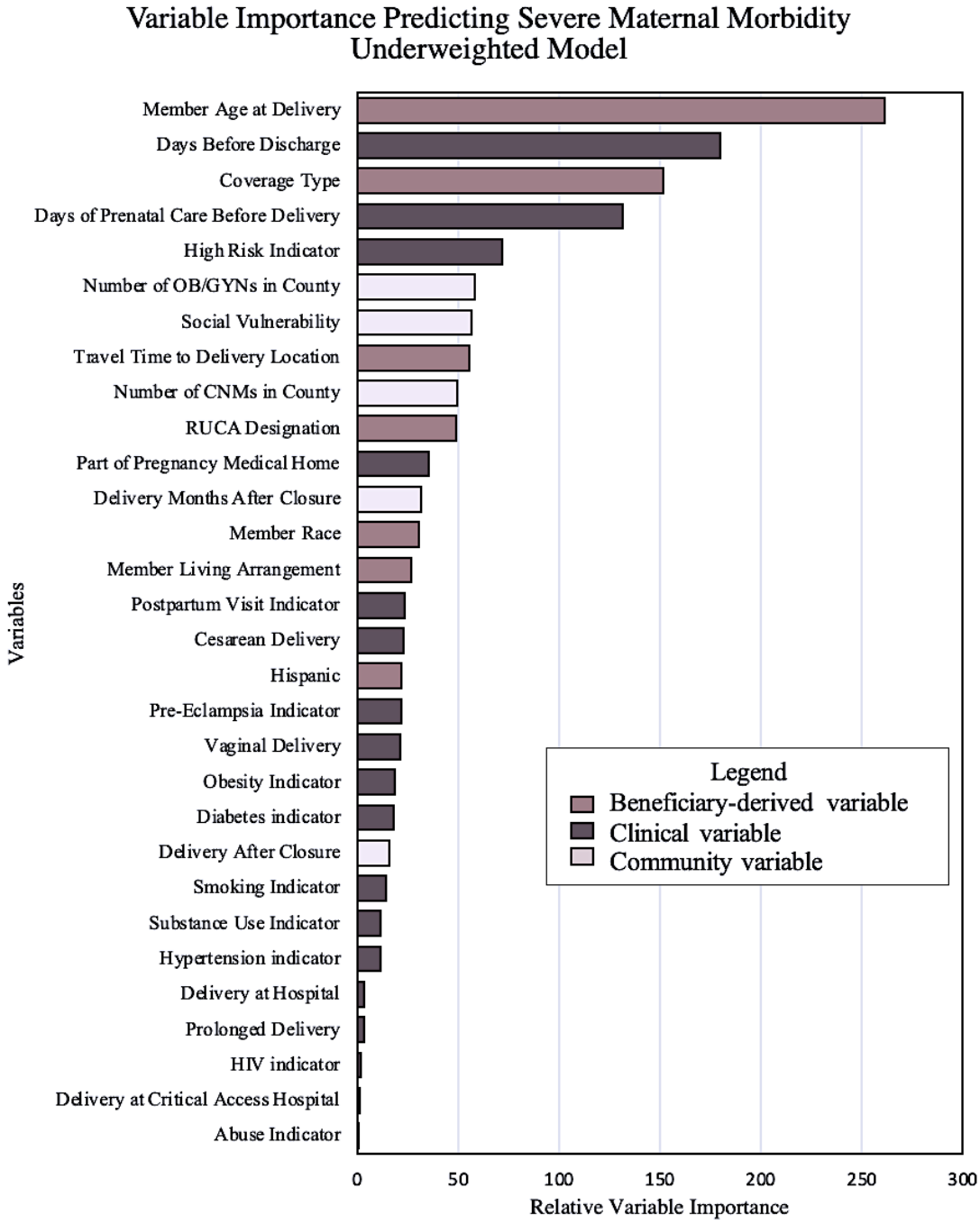
FIGURE 8: ROC CURVE PLOTTING THE TRADEOFF OF THE TRUE-POSITIVE RATE (SENSITIVITY) AND FALSE-POSITIVE RATE (1-SPECIFICITY) AT CLASSIFICATION THRESHOLDS BETWEEN 0 AND 1. THE 45-DEGREE LINE IN THE FIGURE IS THE PERFORMANCE OF A RANDOM CLASSIFIER.



The top ten most predictive factors of severe maternal morbidity were beneficiary age at delivery, days between prenatal care initiation and delivery, days between delivery and discharge from the hospital, number of OB/GYN clinicians in the county, number of Certified Nurse-Midwives in the county, Social Vulnerability Index ranking, RUCA designation, Medicaid coverage type, and travel time (in minutes) to the delivery location (Figure 9). Of the top ten predictors of severe maternal morbidity, the only highly predictive clinical condition was a high-risk pregnancy indicator. Color coding in each importance plot highlights the emphasis of beneficiary and community predictors of severe maternal morbidity. Beneficiary age at the time

of delivery was ranked as the most important predictor variable (relative to other included variables).

FIGURE 9: VISUALIZATION OF RELATIVE VARIABLE IMPORTANCE FOR THE UNDERWEIGHTED MODEL.



Severe Maternal Morbidity Logit Model Results

The top ten predictors from the random forest model included beneficiary-derived variables (rurality, beneficiary age at delivery, travel time to delivery location, type of Medicaid coverage), community variables (number of obstetrics and gynecology providers in the county per 10,000 population, number of certified midwife providers in the county per 10,000 population, and Social Vulnerability Index), and two maternity care variables (number of days between the first prenatal visit and delivery and the number of days the beneficiary was in the hospital before discharge following delivery). Though not in the top list of predictors, race was included in the logit model because of the strong relationships between race and severe maternal morbidity in prior research.

Odds ratios for each variable were similar across both logistic regression models (including all predictor variables and including beneficiary-level variables only) (Table 11). Compared to white women, Black and American Indian and Alaska Native women have lower odds of having a severe morbidity event in both models (holding other covariates constant). Coverage under Medicaid to the Disabled compared to other types of Medicaid increased the odds of a severe morbidity event by 204% in the model with all predictors identified in Aim 2. Every unit increase in the ratio of certified nurse-midwives per population decreased the odds of severe morbidity by 31%. Across each age category, the probability of severe maternal morbidity increases, with women delivering at age 40 and older having 566% higher odds compared to women under 20. Average probabilities of severe maternal morbidity by age and race are presented in Table 12.

TABLE 11: LOGISTIC REGRESSION MODEL OUTPUT PRESENTED AS ODDS RATIOS. DEPENDENT VARIABLE IS THE PROBABILITY OF SEVERE MATERNAL MORBIDITY.

	Predictors			Subset of Beneficiary-Level Predictors		
	All Variables	Without Plan	Without Plan and Travel Time	All Variables	Without Plan	Without Plan and Travel Time
Race (White is Referent)						
Black	0.796*	0.917*	0.889*	0.783*	0.924*	0.907*
	(0.027)	(0.030)	(0.022)	(0.025)	(0.028)	(0.020)
American Indian/Alaskan Native	0.964	0.990	0.850+	0.858	0.921	0.847*
	(0.100)	(0.101)	(0.071)	(0.085)	(0.089)	(0.067)
Other	0.524*	0.573*	0.620*	0.541*	0.578*	0.625*
	(0.065)	(0.069)	(0.051)	(0.060)	(0.063)	(0.046)
RUCA Designation (Metropolitan Core is Referent)						
2. Metropolitan area high commuting	1.008	1.046	1.053	0.926	1.005	1.026
	(0.052)	(0.053)	(0.038)	(0.044)	(0.046)	(0.034)
3. Metropolitan area low commuting	1.008	1.097	1.024	0.849	0.990	0.980
	(0.134)	(0.143)	(0.105)	(0.108)	(0.123)	(0.096)
4. Micropolitan area core	1.086+	1.159*	1.088*	0.964	1.091*	1.039
	(0.053)	(0.055)	(0.039)	(0.042)	(0.046)	(0.033)
5. Micropolitan high commuting	1.076	1.121	1.032	0.943	1.046	0.983
	(0.086)	(0.088)	(0.061)	(0.071)	(0.077)	(0.054)
6. Micropolitan low commuting	0.954	1.049	1.158	0.867	1.021	1.083
	(0.161)	(0.173)	(0.107)	(0.136)	(0.156)	(0.094)
7. Small town core	0.939	1.041	1.037	0.818*	0.961	1.001
	(0.077)	(0.083)	(0.061)	(0.062)	(0.071)	(0.054)
8. Small town high commuting	0.819	0.837	0.852	0.791+	0.846	0.833
	(0.121)	(0.122)	(0.104)	(0.111)	(0.117)	(0.097)
9. Small town low commuting	0.991	1.013	1.019	0.803	0.870	0.952
	(0.185)	(0.185)	(0.131)	(0.141)	(0.149)	(0.112)
10. Rural areas	1.033	1.114	0.931	0.901	1.008	0.891+
	(0.084)	(0.088)	(0.063)	(0.068)	(0.074)	(0.056)
Member Age at Delivery (19 Years or Less Is Referent)						
20-24	1.100	1.059	1.010	1.089	1.006	0.972
	(0.075)	(0.067)	(0.044)	(0.072)	(0.062)	(0.041)
25-29	1.213*	1.175*	1.158*	1.242*	1.145*	1.124*
	(0.083)	(0.074)	(0.051)	(0.082)	(0.070)	(0.047)

30-34	1.367*	1.355*	1.310*	1.398*	1.305*	1.258*
	(0.099)	(0.091)	(0.062)	(0.097)	(0.085)	(0.057)
35-39	1.531*	1.578*	1.539*	1.693*	1.628*	1.537*
	(0.125)	(0.122)	(0.084)	(0.130)	(0.118)	(0.079)
>=40	5.662*	15.545*	12.927*	5.765*	16.408*	13.538*
	(0.401)	(0.955)	(0.562)	(0.395)	(0.980)	(0.566)
Travel Time to Delivery Location	1.001*	1.001*	-	1.001*	1.001*	-
	0.000	0.000	-	0.000	0.000	-
Days Discharged After Delivery	1.000	1.001*	1.001*	-	-	-
	0.000	0.000	0.000	-	-	-
Days of Prenatal Care Before Delivery	1.001*	1.002*	1.002*	-	-	-
	0.000	0.000	0.000	-	-	-
Number of OB/GYNs in County	1.158*	1.126*	1.045+	-	-	-
	(0.040)	(0.039)	(0.026)	-	-	-
Number of CNMs in County	0.725*	0.760*	1.043	-	-	-
	(0.056)	(0.058)	(0.053)	-	-	-
Social Vulnerability Index	0.722*	0.776*	0.892*	-	-	-
	(0.047)	(0.050)	(0.044)	-	-	-
High Risk Pregnancy	1.636*	1.595*	1.285*	-	-	-
	(0.076)	(0.072)	(0.051)	-	-	-
Type of Medicaid Coverage (Work First Family Assistance is referent)						
Medicaid to the Disabled	2.041*	-	-	2.297*	-	-
	(0.282)	-	-	(0.315)	-	-
Medicaid to Families with Dependent Children	0.383*	-	-	0.404*	-	-
	(0.051)	-	-	(0.054)	-	-
Medicaid to Infants and Children	0.429*	-	-	0.445*	-	-
	(0.076)	-	-	(0.078)	-	-
Medicaid to Pregnant Women	0.357*	-	-	0.384*	-	-
	(0.048)	-	-	(0.051)	-	-
Other	4.151*	-	-	4.901*	-	-
	(0.600)	-	-	(0.701)	-	-
Constant	0.020*	0.006*	0.008*	0.023*	0.010*	0.013*
	(0.003)	0.000	0.000	(0.003)	(0.001)	0.000
N	319567	319567	508478	347008	347008	556205

(* p<0.05, ** p<0.01, *** p<0.001); Standard Error in Parentheses

TABLE 12: AVERAGE PROBABILITY OF SEVERE MATERNAL MORBIDITY BY EACH RACE AND AGE CATEGORY FOR ALL LOGISTIC REGRESSION MODELS. ALL PROBABILITIES SIGNIFICANT AT P<0.05.

	Predictors			Subset of Beneficiary-Level Predictors		
Variables	All Variables	Without Plan	Without Plan and Travel Time	All Variables	Without Plan	Without Plan and Travel Time
Race						
White	0.0168	0.0156	0.0182	0.0168	0.0159	0.0187
Black	0.0135	0.0143	0.0163	0.0135	0.0148	0.0170
American Indian/Alaskan Native	0.0146	0.0154	0.0156	0.0146	0.0147	0.0159
Other	0.0095	0.0091	0.0115	0.0095	0.0094	0.0119
Member Age at Delivery						
19 and younger	0.0097	0.0092	0.0117	0.0097	0.0096	0.0122
20-24	0.0107	0.0098	0.0118	0.0106	0.0097	0.0119
25-29	0.0117	0.0108	0.0135	0.0121	0.0110	0.0137
30-34	0.0132	0.0125	0.0152	0.0135	0.0125	0.0153
35-39	0.0140	0.0145	0.0178	0.0163	0.0156	0.0187
40 and older	0.0509	0.1253	0.1315	0.0520	0.1375	0.1434

Using the full model, travel time was further explored by estimating the predicted probability of severe maternal morbidity at specific minute increments. There is a steady positive trend in the predicted probability of a morbidity event for additional minutes of travel time to the delivery location – from 1.21% at 30 minutes to 1.62% at 7 hours (Table 13).

TABLE 13: PREDICTED PROBABILITY OF SEVERE MATERNAL MORBIDITY FOR THE AVERAGE INDIVIDUAL AT SELECT TRAVEL TIMES.

Travel Time (minutes)	**10**	**20**	**30**	**60**	**90**	**120**	**180**	**240**	**300**	**360**	**420**
Predicted Probability of Severe Maternal Mortality	1.21%	1.22%	1.23%	1.25%	1.28%	1.31%	1.37%	1.43%	1.49%	1.56%	1.63%

Discussion

When using machine learning models, we cannot infer causality between the outcome variable and predictor variables. The model simply measures the predictive relationship between two variables. Because the main objective of this paper is to identify predictive factors of severe maternal morbidity, we focused on identifying a model with high sensitivity (i.e., correctly classifying severe maternal morbidity cases) and including a wide range of variables to identify key predictive factors through the variable importance plot. If a similar model were to be implemented as an intervention to identify patients that may experience severe maternal morbidity, further tuning of parameters and cross-validation would likely produce a more overall accurate model (48). Consistent with challenges in screening interventions like cancer screening and clinical tests, a decision about the threshold for false positives requires careful considerations (50). A high rate of false-positive might cost additional money to Medicaid if extra visits or extended coverage were offered to an individual with a high probability of severe maternal morbidity. On the other hand, implementing a low-cost intervention broadly may still be cost-effective if severe maternal morbidity cases are predicted and prevented when possible.

Results from this study suggest that significant predictors of severe maternal morbidity are consistent with highly predictive variables from the random forest model. However, the finding that Black Medicaid beneficiaries have decreased odds of severe maternal morbidity is surprising and inconsistent with highly cited work that found non-Hispanic Black women and American Indian/Alaskan Native women had 2.1 and 1.7 times the rate of severe maternal morbidity as white women (51). The results of this paper may differ because of the difference in the study period, a sample of only North Carolina Medicaid beneficiaries, use of professional and inpatient data, model type, included covariates, and definition of severe maternal morbidity.

At the state and federal levels, new policies and programs are being implemented to address the high rates of maternal morbidity and mortality in the U.S. Maternal Mortality Review Committees (MMRCs) include multidisciplinary teams that review maternal mortality cases and identify causes and factors contributing to the cause of death (52). Expanding these teams to include community members with diversity in the age they delivered, characteristics of the communities they reside in, insurance providers, and other important factors may help identify nonclinical factors that contribute to poor maternal outcomes. Of the 45 states with MMRCs, only two of these states require rural representation on the committee (52). Centers for Medicare & Medicaid Services implemented a structural maternal morbidity measure that asks hospitals to attest to participation and bundle implementation of Statewide or National Perinatal Quality Improvement (Q.I.) Collaborative initiatives in an effort to address high rates of severe maternal morbidity (53). While prepared and well-trained clinicians are an important factor in addressing maternal morbidity and mortality, investment in support services and identification and mitigation of environmental risk factors may also be necessary to address severe maternal morbidity rates. The NCCARE360 network (https://nccare360.org/about/) in North Carolina may be a promising avenue to address support factors that can reduce adverse maternal health outcomes.

Relationship to other Aims

Due to data limitations, distance to prenatal and postpartum services, emergency room visits before and after delivery, and referral to other Medicaid programs were not included in the models although they were found to be important in qualitative interviews. A substantial change in the yearly number of severe maternal morbidity cases was observed between 2015 and 2016. We suspect this change is related to a change in coding associated with the introduction of ICD

10, so we restricted the sample to deliveries after January 1st, 2016 to simplify the interpretation of results. Below is a summary of findings from Aim 2 in relation to other variables identified in Aim 1:

Transportation Availability and Community Integration: Social Vulnerability a top ten predictor variable in the random forest model. Contrary to expectations, the SVI coefficient in the logistic regression model was negative, indicating people in more vulnerable zip codes had lower odds of severe maternal morbidity events.

Remoteness: RUCA designation was a top predictor in the random forest model, but we cannot determine whether more rural or more urban designations were predictive from the logit model.

Distance to the location of delivery: Severe maternal morbidity cases included longer travel times to the location of delivery. Travel Time was also among the top ten predictors in the random forest model.

Type of Medicaid Coverage: Severe maternal morbidity cases had a higher percentage of beneficiaries with Medicaid to the Disabled coverage. Coverage type was also among the top predictors of maternal morbidity in the random forest model. People with Medicaid to the Disabled coverage had higher odds of severe maternal morbidity compared to other coverage types.

Initiation of Prenatal Services: Severe maternal morbidity cases initiated prenatal care earlier in their pregnancies. The number of days between the first prenatal appointment and delivery was a top predictor of severe maternal morbidity in the random forest model.

Receipt of Postpartum Services: Severe maternal morbidity cases had a higher percentage of people with a billed postpartum visit. This indicator was among the top five clinical predictors in the random forest model.

Cesarean Section: Delivery via cesarean section had higher importance than vaginal delivery. We do not have information on whether the cesarean delivery was pre-planned from patient administrative claims.

Observation After Delivery: The number of days a patient was observed in the hospital prior to discharge after delivery was among the top predictors of severe maternal morbidity. On average, severe maternal morbidity cases stayed two days longer in the hospital after delivery. This indicator includes all observation reasons and is not limited to individuals who delivered cesarean section.

In aim 2, maternal morbidity was explored and key factors related to morbidity were identified. In aim 3, econometric models will be used to explore the impact of maternity unit and hospital closures on maternal mortality, a related outcome, controlling for the other variables found to be predictive of maternal morbidity in aims 1 and 2. Treated mothers (i.e., those residing in a zip code associated with a hospital or maternity unit closure) will be compared to a control group of women identified using propensity scores with nearest neighbor matching. Nearest neighbor matching will be determined based on beneficiary characteristics found to be important in aim 2 (RUCA, race, coverage type, age) and the number of weeks before delivery that prenatal care was initiated. Weeks, rather than days, will be used in matching to improve the probability two observations will match. Using the information from aim 2 describing important individual-level predictors of adverse outcomes, analyses in aim 3 will assume two individuals

with similar characteristics, and therefore probabilities of severe maternal morbidity, are well matched for differencing models.

Limitations

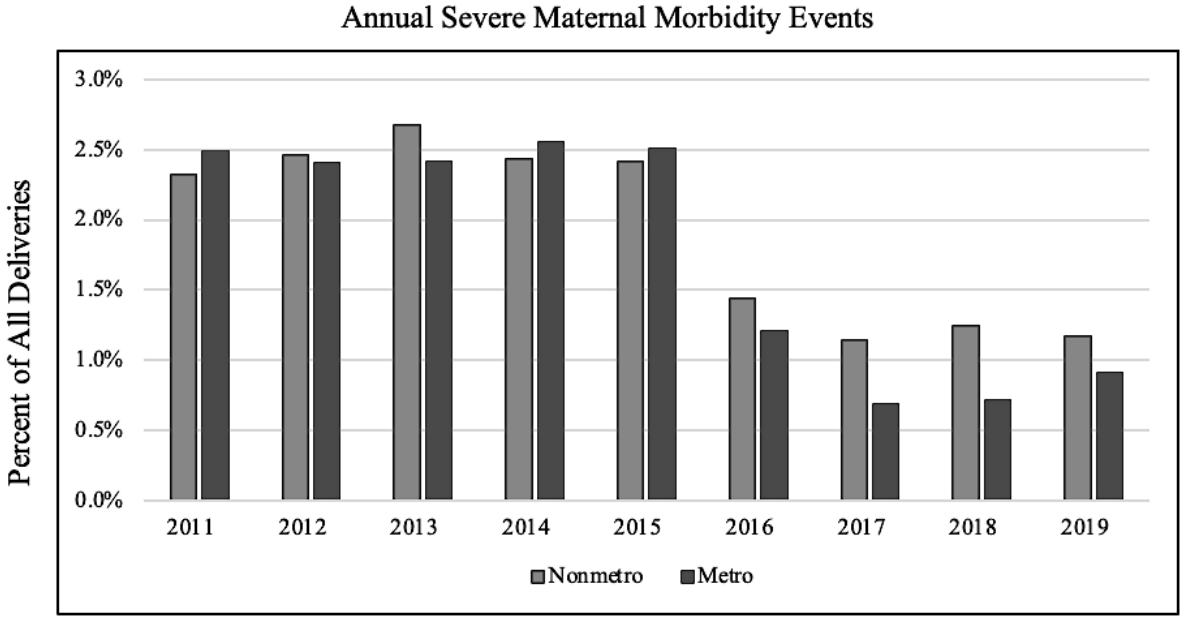
As with all models, the performance and usefulness of machine learning models are dependent on the quality of the inputs. Random forest models tend to inflate the importance of variables with more levels, so we binned continuous variables to limit the number of levels each variable was allowed to split on when constructing trees (41). Further, a substantial number of variables had high rates of missing data, and to keep the observation, we included missing data as a category of splitting. Data quality and constancy in maternal health is a well-documented issue and must be addressed to improve the utility and accuracy of models using this data (54, 55).

Random forest is not the only classification model that could be used for classification research questions. Other classification algorithms include logistic regression, naive Bayes, k-nearest neighbor, support vector machines, and other statical packages and versions of tree models. We did not explore the accuracy of other models because we were interested in the variable importance plot with Gini importance, the calculation of importance most appropriate for this research question, which is not a universal feature of tree algorithms such as XGBoost. While these models were not appropriate for variable importance calculations, they may produce more accurate predictions. Systems with more computational capacity would also allow for more advanced and complex model specifications that could improve model performance (43). Variable transformations (e.g., age to age squared, logarithmic transformations for skewed data) could also be included in machine learning models, allowing the model to identify whether these

transformations or combinations of variables and their transformations better discriminate between outcome states.

North Carolina Medicaid restricts postpartum coverage to 60 days after delivery for individuals covered under the Medicaid for Pregnant Women program, so post-delivery time variables, such as days between delivery and the postpartum visit, were not calculated. Before 2015, annual trends in severe maternal morbidity showed similar rates of morbidity for both metro (RUCA<=3) and nonmetro (RUCA >=4) residents (Figure 10). However, beginning in 2016, rates of severe maternal morbidity became more prevalent for nonmetro residents. Between 2011 and 2019, the overall rate of a severe maternal morbidity event in North Carolina was 1.83% of all Medicaid deliveries. Before 2016, this rate was 2.47% and after 2016, only 0.99%. Further exploration into the CDC coding scheme of maternal morbidity (34), NC Medicaid billing documents and practices, and investigation into the jump in relative nonmetro events is necessary to explain observed trends in years after 2016.

FIGURE 10: TRENDS IN SEVERE MATERNAL MORBIDITY BY RURAL AND URBAN ZIP CODE OF RESIDENCE AT DELIVERY. PRESENTED AS THE PERCENT OF SEVERE MATERNAL MORBIDITY CASES OUT OF DELIVERIES PER YEAR.



Policy Implications and Future Research

The results of the random forest models suggest characteristics of the beneficiary, the community in which the beneficiary lives, and the amount of observation time, either through a long relationship with prenatal care providers or observation after delivery are the most predictive factors of severe maternal morbidity. Little research has focused on the environmental factors that contribute to clinical maternal morbidity outcomes. These models do not tell us about the mechanism through which these factors affect severe maternal morbidity, and further research into these potential pathways should be explored. The place-based literature on tobacco and alcohol control may offer a framework to better understand how the environment of an individual affects their maternity care outcomes. Cost-effectiveness studies on implementing predictive models for identifying individuals at risk of severe maternal morbidity are required to understand whether beneficiaries would benefit from a policy intervention of this type.

AIM 3: RURAL AND MINORITY COMMUNITIES WITH MEDICAID COVERAGE ARE UNEQUALLY AFFECTED BY MATERNITY UNIT CLOSURES IN NORTH CAROLINA

Background

Rural communities vary in resilience and the availability of resources to address and respond to health system changes like a maternity unit closure (27). Studies have attempted to identify the impact restricted access for rural residents has on patient outcomes, health care costs, and rural communities. Still, the intricacy of the rural health service infrastructure poses unique challenges. Little research has been done on the impact of maternity unit closures and variation of maternal health outcomes within rural communities (2, 6, 7).

Previous research finds the closure of maternity unit services is associated with a 3.06 percentage point increase in the probability of delivering in a hospital without obstetric services (38), reduced access to postpartum care (56), late initiation of prenatal services (39, 57), 9% greater probability of pregnancy-related death (8), and a 0.67 percentage point increase in the likelihood of preterm birth (38). Closures are also associated with increased rates of labor induction and infant mortality (56, 58). Compounding these findings, late initiation of prenatal services is positively associated with infant mortality (59) and makes the individual 3-4 times more likely to die because of a pregnancy-related condition (60). Longer travel time to delivery locations also make an individual 1.3 times as likely to have an induced labor (60). From interviews from 19 communities that experienced a maternity unit closure at the local hospital, most of the communities were able to continue providing prenatal care through family physicians and primary care providers, but postpartum care was more difficult to access (61). The majority

of maternal mortality cases occur after the mother and baby are discharged from the hospital. Relatively few maternal deaths occur during childbirth itself (62), making the coordination of care between the delivery and postpartum care a very important linkage.

Disparities in maternal morbidity and mortality persist among racial groups, insurance payers, and urban and rural women. Black women are three times more likely to die during childbirth than white women, and Black infants are twice as likely than white infants to die during their first year (7, 38). Some evidence suggests Black women have higher-risk pregnancies due to their health status and health behaviors, but other studies suggest systemic racism in the health care system drives disparities (7, 15, 38, 62-64).

This study will explore how the intersection of race and rurality predicts maternal mortality to better understand characteristics of communities with a high mortality burden. We will also extend work on the effect of hospital-based maternity unit closures on travel time to identify rural and race interactions. Finally, we will further explore the impact of hospital-based maternity closures on mortality by calculating the probability of death for individuals with varying racial and rural demographic characteristics.

Methods

Medicaid deliveries between January 1st, 2011 and December 31st 2019 in North Carolina were identified and member claims one year before the delivery date and one year after the delivery date were compiled to create a patient profile. This paper explores two outcomes of interest in separate sets of models – maternal mortality and travel time to delivery location. Mortality (binary) in this study is defined as death within one year of delivery, consistent with definitions of maternal mortality (Table 14). Maternal mortality, by definition, is a death related to an individual's pregnancy or caused by conditions aggravated by their pregnancy (65).

However, determining if each death qualifies as a maternal mortality event requires an intense review of each patient's medical records. This determination process is beyond the scope of this study and the time and knowledge capacity of the investigator (58, 65). Travel time was described as a source of stress during pregnancy in Aim 1, which may impact the pregnancy, care-seeking behavior, and maternal health outcomes. Travel time represents the number of minutes it takes to drive from the center of the individual's zip code of residence at the time of delivery to the center of the delivery location zip code.

TABLE 14: LISTS OF VARIABLES, SOURCES, AND DESCRIPTION OF HOW EACH VARIABLE IS CONSTRUCTED.

Variable	**Source**	**Construction**
Outcome Variables		
Variable	Source	Construction
Death During Postpartum Period	Medicaid Member file	Death date in member file within 365 days of delivery date. Reason for death is not restricted to maternity-related deaths.
Travel Time	Medicaid member file; NPI files with Zip code of Delivery Billing Provider	Geocoded zip code centroids using HERE and georoute in Stata. Variable is minutes driving between centroids.
Model Variables		
Age at time of delivery	Medicaid member file	Continuous; Derived from member birthdate and day of delivery; Restricted to ages 12-55 based on criteria from CDC severe maternal morbidity guidance; In categorical representations, age was converted into one of the following categories: ≤ 19, 20–24, 25–29, 30–34, 35–39, and ≥ 40
Race	Medicaid member file	Categorical; Race collapsed to identify all individuals who identified as White, Black, Native American/Alaskan Native, or other remaining categories. If any of the race variable indicated Black or Native American, the member was included in those categories.
RUCA Designation	Medicaid member file; 2010 Rural-Urban Commuting Area (RUCA) Codes Economic Research Service U.S. Department of Agriculture	Categorical; Member zip codes matched to RUCA zip (level one RUCA code only)

Medicaid Coverage Type	Medicaid member file	Categorical; Collapsed to Medicaid to the Disabled, Medicaid to Families with Dependent Children, Medicaid to Infants and Children, Medicaid to Pregnant Women, and Other
Closure Community	Medicaid member file; NPI files with Zip code of Delivery Billing Provider, Closure List	Categorical; collection of zip codes based on pre-closure market area and further restricted to a 30-mile radius
Weeks of Prenatal Care	Claim Service Dates	Continuous; Number of days between first prenatal billing code and delivery date divided by 7
Descriptive Variables		
Variable	Source	Construction
High Risk Pregnancy	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; Diagnosis Codes that Substantiate High-Risk Deliveries for Maternal Stand-by Service
Vaginal Delivery	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; All DRG and CPT codes that indicate vaginal delivery
Cesarean Delivery	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; All DRG and CPT codes that indicate cesarean delivery
Complications from pre-eclampsia during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from substance use during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from sexually transmitted diseases during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from smoking during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from diabetes during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from obesity during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from hypertension during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from anemia during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Complications from abuse at home during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual

Complications from HIV during pregnancy	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Prenatal care initiation	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5, ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Individual and global codes that indicate a prenatal event occurred
Prenatal care intensity	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; Code for 4-6 Visits, Code for 7+ Visits
Postpartum visit	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5, ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Individual and global codes that indicate a postpartum event occurred
Delivery Complications related to exhaustion	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Preterm Delivery	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Derived from ICD Manual
Same provider for all prenatal, delivery, and postpartum encounters	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Binary; Global code billed by provider that indicates all services provided
Referred to other Medicaid programs for pregnant women	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-5	Codes for referral to Dietary Evaluation and Counseling and Medical Lactation Services, Enhanced Mental Health and Substance Abuse Services, and Health and Behavior Intervention Services
Included in a Pregnancy Medical Home	NC Medicaid Obstetric Services Clinical Coverage Policy No.: 1E-6	Binary; Referral codes and codes billed by Pregnancy Medical Home
Emergency Department Visits	ICD-9-CM/ICD-10-CM/PCS Codes	Binary; Revenue code for Emergency Room with before and after delivery date indicator
Days Before Discharge After Delivery	Claim Service Dates	Continuous; Number of days after delivery patient was discharged
Location of Delivery	Taxonomy of Billing Provider	Categorical; Derived from billing provider taxonomy
Ethnicity	Medicaid member file	Binary; Ethnicity collapsed to indicate Hispanic ethnicity if any ethnicity is selected
Living Arrangement	Medicaid member file	Categorical; Collapsed to private living arrangement and other
Medicaid Coverage Type	Medicaid member file	Categorical; Collapsed to Medicaid to the Disabled, Medicaid to Families with Dependent Children, Medicaid to Infants and Children, Medicaid to Pregnant Women, and Other

Number of Obstetricians and Gynecologists in county per 10,000 population	North Carolina Health Professions Data System, Program on Health Workforce Research and Policy, Cecil G. Sheps Center for Health Services Research, University of North Carolina at Chapel Hill	Continuous; County-level rates matched to member county; Data years matched to delivery years
Number of Certified Nurse Midwives in county per 10,000 population	North Carolina Health Professions Data System, Program on Health Workforce Research and Policy, Cecil G. Sheps Center for Health Services Research, University of North Carolina at Chapel Hill	Continuous; County-level rates matched to member county, Data years matched to delivery years; 2011 and 2012 data unavailable and replaced with 2013 data
Social Vulnerability Index	Medicaid member file; CDC/ATSDR Social Vulnerability Index North Carolina Overall SVI Ranking by zip code	Continuous; Delivery Years 2011-2014 matched at county level to 2014 SVI, 2015-2016 matched to 2016 SVI, all other years matched to 2018 SVI
Number of months delivering after local maternity unit closure	Medicaid member file; Maternity Unit Closure List (Appendix 4)	Continuous; Calculated months between closure month and year and delivery month and year

We used an event study design with relative time values before and after treatment to estimate the impact of a maternity unit closure in a community. Closure communities were created from an internal list of North Carolina maternity unit closures, including both complete hospital closures and hospital-based maternity unit closures. Closure communities were developed by identifying the pool of resident zip codes delivering at a hospital prior to closure and refining the list of zip codes to those within 30 minutes of driving. The month and year of each closure was used to identify individuals that would have delivered at each closed unit using delivery dates and the collection of zip codes that delivered prior to closure.

Using the closure community designations, each individual was assigned a new relative time value representing the difference between the individual's delivery month-year and the month-year of the hospital or maternity unit closure. Negative time values indicated that the individual delivered before the closure, and positive values indicated that the individual delivered after the closure. In this process, we assume individuals in the "treated" group, would

behave similarly after closure as compared to individuals delivering in the same community before closure. To identify a control group, we used the *teffects* package in Stata to identify groups of individuals with similar individual characteristics through nearest-neighbor matching (66). Variables used in the matching process were derived from Aim 2 findings and included beneficiary age at the time of delivery, RUCA designation to account for remoteness, Medicaid coverage type, race due to documented differences in maternal health outcome by race, and the number of weeks between the initiation of prenatal care and the delivery date of the individual. Prenatal and beneficiary-derived variables were used to establish a baseline of similar individuals in the matching process to avoid issues from the timing of the matching and outcome variables of interest (i.e., travel time to delivery location and death after delivery occur after prenatal care variables and beneficiary characteristics are time-invariant). During the matching process, each matched pair was forced to have a delivery date within the same month-year combination. The control observation in each team was assigned the same relative time value as the treated observation. Only treated observations with control group matches were used in the final analysis.

Indicators for pre-post periods, treatment (i.e., closure), and the type of treatment (i.e., hospital closure or maternity-unit closure) were created for analysis. Each of the two outcomes was used in six event study models – a model with treatment, a model with treatment for maternity unit closures only, a model with treatment for a hospital closure only, and versions of each of these models with a year since treatment fixed effect. The treatment effect is estimated using binary indicators of treatment and intervention periods represented by:

$$Y = \beta 0 + \beta 1*[\text{Post closure}] + \beta 2*[\text{Treatment}] + \beta 3*[\text{Post closure}*\text{Treatment}] + \beta 4*[\text{Covariates}] + \varepsilon$$

Additional descriptive variables not used in the models are included in Tables 14 and 15 to provide additional context on the potential differences between treatment groups. Individual units are not repeated over time over the study period (i.e., no variation within the unit of analysis), so we cannot include individual fixed effects required of two-way-fixed-effects estimators and newly proposed difference-in-differences estimators.

Results

Treated and control sample characteristics are presented in Table 15. Compared to the control group, more beneficiaries in the treatment group resided in more rural zip codes and delivered at Critical Access Hospitals. Despite statistically significant differences, matched variables had similar practical values across the two groups. For example, the average age for both the treatment and control groups rounds to 26 ($p<0.001$).

TABLE 15: CHARACTERISTICS OF CONTROL AND TREATMENT GROUPS. HOSPITAL CLOSURES AND MATERNITY UNIT CLOSURES ARE JOINTLY PRESENTED AS THE TREATED GROUP FOR COMPARISON PURPOSES.

Predictor Variable	Control		Treated (Closure)		P-Value	Missing
Total Deliveries	N=152,126		N=142,931			
Member Age at Delivery	25.93879	(5.992551)	26.07495	(6.172348)	<0.001	7554
Member Living Arrangement						
Private Living Arrangement	151,724	(99.7%)	142,528	(99.7%)	0.070	1297
Other	402	(0.3%)	403	(0.2%		
High Risk Indicator	10,076	(6.6%)	9,832	(6.9%)	0.006	0
Member Race						
White	99,091	(65.1%)	89,888	(62.9%)	<0.001	
Black	47,531	(31.2%)	47,395	(33.2%)		
American Indian/Alaskan Native	3,552	(2.3%)	3,584	(2.5%)		
Other	1,952	(1.3%)	2,064	(1.4%)		
RUCA Designation						
1. Metropolitan area core	84,252	(55.4%)	71,959	(50.3%)	<0.001	22117
2. Metropolitan area high commuting	21,240	(14.0%)	21,217	(14.8%)		
3. Metropolitan area low commuting	2,516	(1.7%)	1,769	(1.2%)		
4. Micropolitan area core	22,753	(15.0%)	23,017	(16.1%)		
5. Micropolitan high commuting	8,201	(5.4%)	5,520	(3.9%)		
6. Micropolitan low commuting	1,084	(0.7%)	1,039	(0.7%)		
7. Small town core	6,562	(4.3%)	7,000	(4.9%)		
8. Small town high commuting	866	(0.6%)	2,493	(1.7%)		
9. Small town low commuting	516	(0.3%)	2,333	(1.6%)		
10. Rural areas	4,136	(2.7%)	6,584	(4.6%)		
Hispanic	29,470	(19.4%)	21,208	(14.8%)	<0.001	0
Travel Time to Delivery Location	30.26212	(55.87657)	28.91272	(31.03295)	<0.001	106762
Social Vulnerability	.4619249	(.239886)	.5200853	(.2851855)	<0.001	249
Vaginal Delivery	108,409	(71.5%)	99,730	(70.0%)	<0.001	912
Cesarean Delivery	43,186	(28.5%)	42,820	(30.0%)	<0.001	912
Part of Pregnancy Medical Home	25,746	(16.9%)	24,109	(16.9%)	0.68	0
Same Provider for All Encounters	768	(0.5%)	809	(0.6%)	0.023	0
Prenatal Visit Indicator	152,126	(100.0%)	142,931	(100.0%)	0.33	0
Postpartum Visit Indicator	87,907	(57.8%)	81,846	(57.3%)	0.004	0
Prolonged Delivery	5,339	(3.5%)	4,890	(3.4%)	0.19	0
Smoking Indicator	10,136	(6.7%)	9,374	(6.6%)	0.25	0

Substance Use Indicator	6,101	(4.0%)	5,243	(3.7%)	<0.001	0
Obesity Indicator	12,298	(8.1%)	9,515	(6.7%)	<0.001	0
STD Indicator	1,616	(1.1%)	1,355	(0.9%)	0.002	0
Diabetes indicator	5,670	(3.7%)	5,105	(3.6%)	0.024	0
Hypertension indicator	4,970	(3.3%)	4,531	(3.2%)	0.14	0
Anemia Indicator	7,538	(5.0%)	7,055	(4.9%)	0.81	0
Abuse Indicator	135	(0.1%)	166	(0.1%)	0.020	0
HIV indicator	1,765	(1.2%)	1,369	(1.0%)	<0.001	0
Pre-Eclampsia Indicator	3,915	(2.6%)	3,659	(2.6%)	0.82	0
Days of Prenatal Care Before Delivery	188.9057	(86.40822)	187.9221	(86.15167)	0.002	0
Delivery at Hospital	149,477	(98.3%)	138,979	(97.2%)	<0.001	0
Delivery at Critical Access Hospital	2,113	(1.4%)	3,565	(2.5%)	<0.001	0
Number of OB/GYNs in County	1.021399	(.6293961)	.9586362	(.5376964)	<0.001	249
Number of CNMs in County	.2796032	(.2558759)	.2295171	(.2501459)	<0.001	249
Delivery Months After Closure	-	-	23.43571	(15.20074)	-	248909
Closure Community Type						
Hospital with Maternity Unit	-	-	83,582	(58.5%)	-	152126
Maternity Unit	-	-	59,349	(41.5%)		
Days Discharged After Delivery	5.606153	(31.36451)	5.631996	(31.27453)	0.82	1297
Member Plan Type						
Work First Family Assistance	1,622	(1.1%)	1,956	(1.4%)	<0.001	0
Medicaid to the Disabled	4,065	(2.7%)	4,471	(3.1%)		
Medicaid to Families with Dependent Children	68,716	(45.2%)	62,061	(43.4%)		
Medicaid to Infants and Children	4,584	(3.0%)	4,283	(3.0%)		
Medicaid to Pregnant Women	72,729	(47.8%)	69,819	(48.8%)		
Other	410	(0.3%)	341	(0.2%)		

Note: Data are presented as mean (SD) for continuous measures, and n (%) for categorical measures.
(* p<0.05, ** p<0.01, *** p<0.001)

TABLE 16: REGRESSION COEFFICIENTS FOR TRAVEL TIME MODELS. STANDARD ERRORS IN PARENTHESES. TIME FIXED EFFECT IS OMITTED.

Variables	Travel Time All Closures	Travel Time Hospital Closures	Travel Time Maternity Unit Closures	Travel Time All Closures With Covariates	Travel Time Hospital Closures With Covariates	Travel Time Maternity Unit Closures With Covariates
Closure Group Indicator	-0.476	-0.009	-0.285	-2.074***	-0.578	-3.359***
	(0.250)	(0.465)	(0.580)	(0.245)	(0.452)	(0.576)
After Closure Indicator	-3.467***	0.681	-6.326***	-0.059	0.663	-1.339
	(0.742)	(1.913)	(1.726)	(0.709)	(1.825)	(1.646)
Closure Group*After Closure Indicator	2.069***	1.128	4.132***	2.600***	0.450	5.485***
	(0.427)	(0.715)	(1.227)	(0.409)	(0.682)	(1.170)
Member Race						
Black	-	-	-	-2.667***	-2.145***	-3.975***
	-	-	-	(0.275)	(0.453)	(0.811)
American Indian/Alaskan Native	-	-	-	-0.444	-1.417	-1.070
	-	-	-	(1.378)	(2.285)	(3.775)
Other	-	-	-	-4.464***	-4.971**	-4.748
	-	-	-	(1.007)	(1.712)	(2.813)
RUCA Designation						
2. Metropolitan area high commuting	-	-	-	15.904***	16.315***	15.641***
	-	-	-	(0.351)	(0.596)	(0.888)
3. Metropolitan area low commuting	-	-	-	10.154***	12.277***	12.387***
	-	-	-	(1.132)	(2.795)	(2.218)
4. Micropolitan area core	-	-	-	0.467	2.301***	-2.650**
	-	-	-	(0.359)	(0.620)	(0.830)
5. Micropolitan high commuting	-	-	-	9.422***	12.782***	7.586***
	-	-	-	(0.568)	(1.193)	(1.151)
6. Micropolitan low commuting	-	-	-	13.438***	14.322***	16.141***
	-	-	-	(1.536)	(3.738)	(2.792)
7. Small town core	-	-	-	3.476***	3.864**	3.374**
	-	-	-	(0.607)	(1.301)	(1.189)
8. Small town high commuting	-	-	-	15.064***	14.200***	17.931***
	-	-	-	(0.886)	(2.492)	(1.457)
9. Small town low commuting	-	-	-	17.191***	16.057***	18.745***
	-	-	-	(1.469)	(3.409)	(2.437)

10. Rural areas	-	-	-	29.993***	32.828***	29.206***
	-	-	-	(0.572)	(1.769)	(0.984)
Race and RUCA Interaction						
Other*2. Metropolitan area high commuting	-	-	-	-1.006	0.372	-0.353
	-	-	-	(3.370)	(4.659)	(9.999)
Other*3. Metropolitan area low commuting	-	-	-	-1.711	-14.310	20.446
	-	-	-	(15.862)	(17.767)	(30.448)
Other*4. Micropolitan area core	-	-	-	-0.080	3.694	9.606
	-	-	-	(2.813)	(4.659)	(6.324)
Other*5. Micropolitan high commuting	-	-	-	2.013	-2.542	8.039
	-	-	-	(6.932)	(10.294)	(30.392)
Other*7. Small town core	-	-	-	-6.284	1.440	-9.944
	-	-	-	(6.382)	(14.418)	(11.826)
Other*8. Small town high commuting	-	-	-	-14.948	-10.359	-19.525
	-	-	-	(10.422)	(17.721)	(21.608)
Other*9. Small town low commuting	-	-	-	-7.170	-	-6.688
	-	-	-	(9.831)	-	(15.570)
Other*10. Rural areas	-	-	-	-9.739	-10.715	-10.813
	-	-	-	(6.221)	(14.469)	(10.006)
Black*2. Metropolitan area high commuting	-	-	-	3.828***	4.154***	5.201**
	-	-	-	(0.666)	(1.019)	(2.014)
Black*3. Metropolitan area low commuting	-	-	-	4.625*	3.910	11.625*
	-	-	-	(2.084)	(4.363)	(4.629)
Black*4. Micropolitan area core	-	-	-	-3.042***	-3.565***	-2.308
	-	-	-	(0.573)	(0.916)	(1.535)
Black*5. Micropolitan high commuting	-	-	-	2.616*	-0.133	-0.277
	-	-	-	(1.125)	(1.916)	(2.648)
Black*6. Micropolitan low commuting	-	-	-	2.456	2.250	-2.534
	-	-	-	(2.743)	(5.201)	(7.194)
Black*7. Small town core	-	-	-	3.453***	4.052*	3.160
	-	-	-	(0.946)	(1.867)	(1.979)
Black*8. Small town high commuting	-	-	-	4.012	-3.830	6.796
	-	-	-	(2.165)	(6.343)	(3.761)
Black*9. Small town low commuting	-	-	-	3.158	-1.381	5.729
	-	-	-	(2.117)	(4.409)	(3.562)
Black*10. Rural areas	-	-	-	-1.130	2.249	-5.274*
	-	-	-	(1.216)	(2.662)	(2.440)

AI/AN*2. Metropolitan area high commuting	-	-	-	0.315	2.063	-2.866
	-	-	-	(2.311)	(3.405)	(6.347)
AI/AN*3. Metropolitan area low commuting	-	-	-	0.809	-4.149	3.923
	-	-	-	(2.277)	(4.080)	(6.384)
AI/AN*4. Micropolitan area core	-	-	-	-3.390	-1.793	-3.236
	-	-	-	(1.924)	(3.550)	(4.639)
AI/AN*5. Micropolitan high commuting	-	-	-	4.318*	-0.201	9.484
	-	-	-	(2.100)	(3.515)	(6.389)
AI/AN*6. Micropolitan low commuting	-	-	-	23.181	-	-
	-	-	-	(27.427)	-	-
AI/AN*7. Small town core	-	-	-	3.236	33.906**	-4.339
	-	-	-	(4.860)	(10.419)	(9.578)
AI/AN*8. Small town high commuting	-	-	-	1.765	-	12.673
	-	-	-	(8.800)	-	(14.109)
AI/AN*9. Small town low commuting	-	-	-	9.227	-	8.765
	-	-	-	(13.821)	-	(15.765)
AI/AN*10. Rural areas	-	-	-	17.720***	20.595***	20.355***
	-	-	-	(2.257)	(5.483)	(5.087)
Constant	31.449***	27.759***	33.179***	25.445***	23.899***	26.648***
	(0.587)	(1.765)	(1.094)	(0.582)	(1.710)	(1.101)
N	82047	22606	17460	82047	22606	17460

Note: AI/AN, American Indian or Alaskan Native
(* p<0.05, ** p<0.01, *** p<0.001)

TABLE 17: LOGISTIC REGRESSION MODEL ODDS RATIOS FOR POST-DELIVERY DEATHS AFTER CLOSURE MODELS. TIME FIXED EFFECT IS OMITTED.

Variables	Deaths After All Closures	Deaths After Hospital Closures	Deaths After Maternity Unit Closures	Deaths After All Closures with Covariates	Deaths After Hospital Closures with Covariates	Deaths After Maternity Unit Closures with Covariates
Closure Group Indicator	1.170	0.818	1.256	1.147	0.786	1.219
	(0.119)	(0.230)	(0.274)	(0.120)	(0.231)	(0.280)
After Closure Indicator	1.587	0.651	3.209	1.754	0.686	3.200
	(0.437)	(0.506)	(0.761)	(0.438)	(0.506)	(0.767)
Closure Group and After Closure Indicator	1.481+	2.529*	1.019	1.517+	2.651*	1.095
	(0.220)	(0.416)	(0.539)	(0.221)	(0.416)	(0.541)
Member Race						
Black	-	-	-	1.492*	1.445+	0.958
	-	-	-	(0.104)	(0.190)	(0.283)
American Indian/Alaskan Native	-	-	-	1.212	2.366+	0.498
	-	-	-	(0.320)	(0.456)	(1.017)
Other	-	-	-	2.012*	0.685	3.401*
	-	-	-	(0.342)	(1.011)	(0.600)
RUCA Designation						
2. Metropolitan area high commuting	-	-	-	1.260	1.564+	0.496
	-	-	-	(0.146)	(0.240)	(0.529)
3. Metropolitan area low commuting	-	-	-	1.234	1.667	1.925
	-	-	-	(0.428)	(0.673)	(0.734)
4. Micropolitan area core	-	-	-	1.197	1.330	0.894
	-	-	-	(0.143)	(0.257)	(0.362)
5. Micropolitan high commuting	-	-	-	1.578*	1.616	2.316*
	-	-	-	(0.220)	(0.440)	(0.380)
6. Micropolitan low commuting	-	-	-	2.239+	4.349*	1.790
	-	-	-	(0.455)	(0.726)	(1.022)
7. Small town core	-	-	-	1.265	1.923	0.977
	-	-	-	(0.232)	(0.433)	(0.483)

8. Small town high commuting	-	-	-	0.752	-	0.981
	-	-	-	(0.584)	-	(0.733)
9. Small town low commuting	-	-	-	1.085	-	2.361
	-	-	-	(0.508)	-	(0.614)
10. Rural areas	-	-	-	1.464	0.003	1.597
	-	-	-	(0.249)	(0.721)	(0.398)
Constant	0.001*	0.003*	0.001*	0.001*	0.002*	0.001*
	(0.360)	(0.275)	(0.533)	(0.370)	(0.307)	(0.562)
N	129427	37024	25943	129427	36617	25943

(+ p<0.10, * p<0.05)

TABLE 18: AVERAGE PROBABILITY OF MORTALITY BY EACH RACE CATEGORY.

Race	**All Closure Types**		**Hospital Closure**	
	Probability	95% Confidence Interval	Probability	95% Confidence Interval
White	0.00281	(0.00210, 0.00352)	0.00268	(0.00233, 0.00303)
Black	0.00401	(0.00296, 0.00514)	0.00400	(0.00338, 0.00462)
AI/AN	0.00661	(0.00101, 0.01221)	0.00325	(0.00127, 0.00523)
Other	0.00193	(-0.00185, 0.00570)	0.00535	(0.00187, 0.00890)

Travel Time

Compared to Medicaid beneficiaries residing in metro zip codes, the median number of traveling minutes to the delivery location was 10 minutes longer for beneficiaries residing in nonmetro zip codes. The minimum for both metro and nonmetro zip codes is around 15 minutes, but the maximum for nonmetro zip codes was over an hour and a half compared to less than an hour in metro communities. Control and treated groups were more similar, with maximums of a little over an hour and under an hour and fifteen minutes, respectively (Figures 11 and 12).

FIGURE 11: COMPARISON OF TRAVEL TIMES TO DELIVERY LOCATION BETWEEN MEDICAID MEMBERS WITH METRO AND NONMETRO ZIP CODES. OUTLIERS ARE REMOVED FROM THE PLOT.

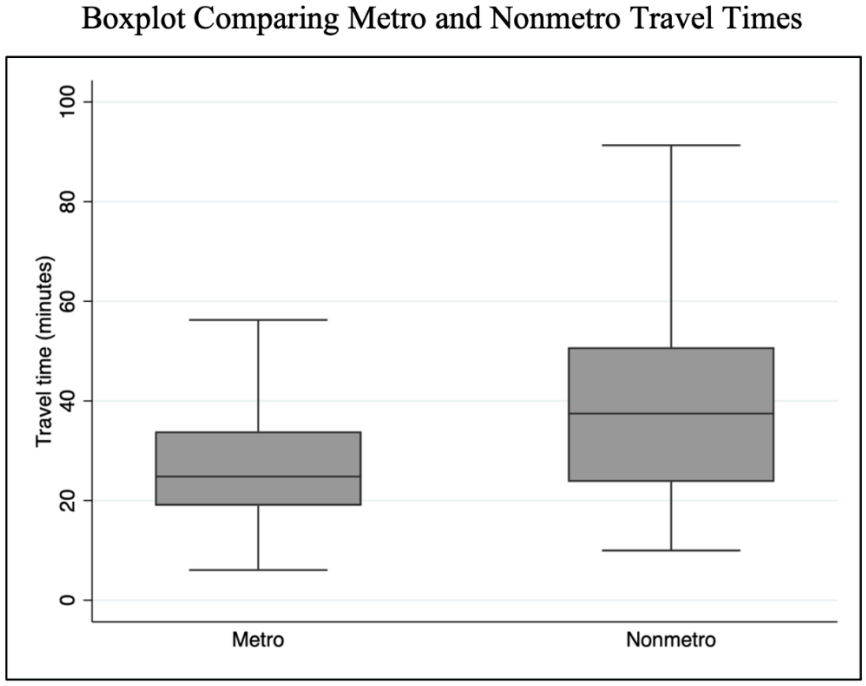
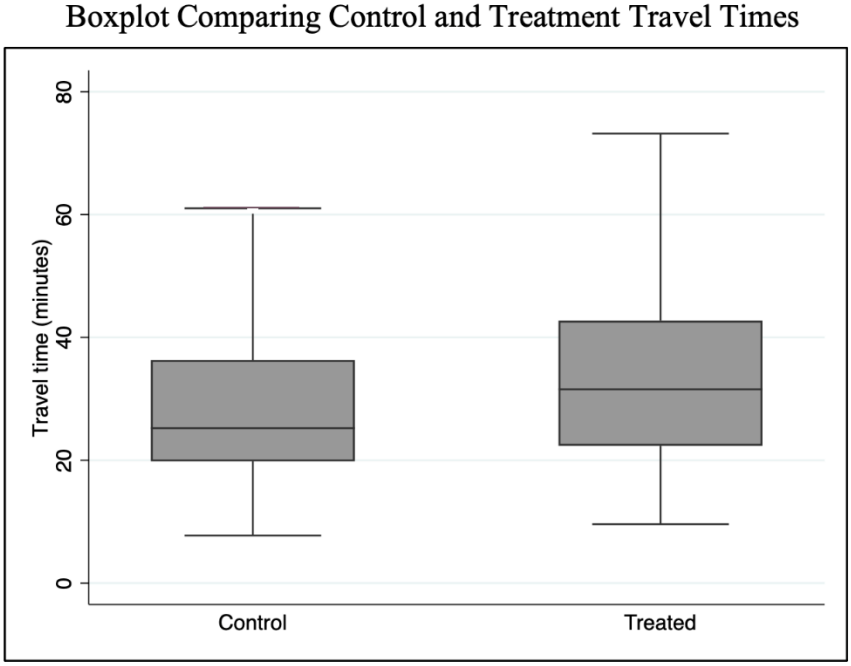


FIGURE 12: COMPARISON OF TRAVEL TIMES TO DELIVERY LOCATION BETWEEN MEDICAID MEMBERS IN TREATMENT AND CONTROL GROUPS. OUTLIERS ARE REMOVED FROM THE PLOT.

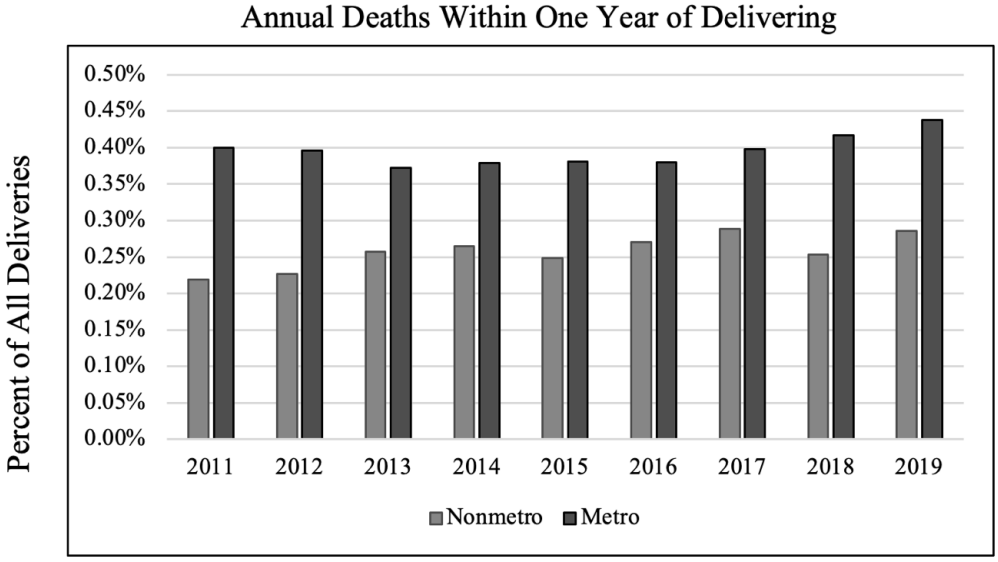


Models where the treatment was all closures (i.e., hospitals and maternity units) and maternity unit closures only both had significant first difference estimators (i.e., delivery after closure interacted with treatment) (Table 16). When the treatment was defined as all closures, the treatment group saw a 4.1-minute increase in travel time to the delivery location. When the treatment was limited to maternity unit closures, incremental travel time increased to 5.5 minutes. Compared to white beneficiaries, Black beneficiaries traveled fewer minutes, but this trend does not hold across all levels of metro and non-metro. Native American beneficiaries in the most rural communities traveled an additional 20 minutes following a maternity unit closure compared to white beneficiaries in metropolitan counties. With some exceptions, beneficiaries with increasingly remote zip codes had longer travel times, up to an average of about 30 minutes longer when compared to beneficiaries in metropolitan zip codes.

Mortality Following Delivery

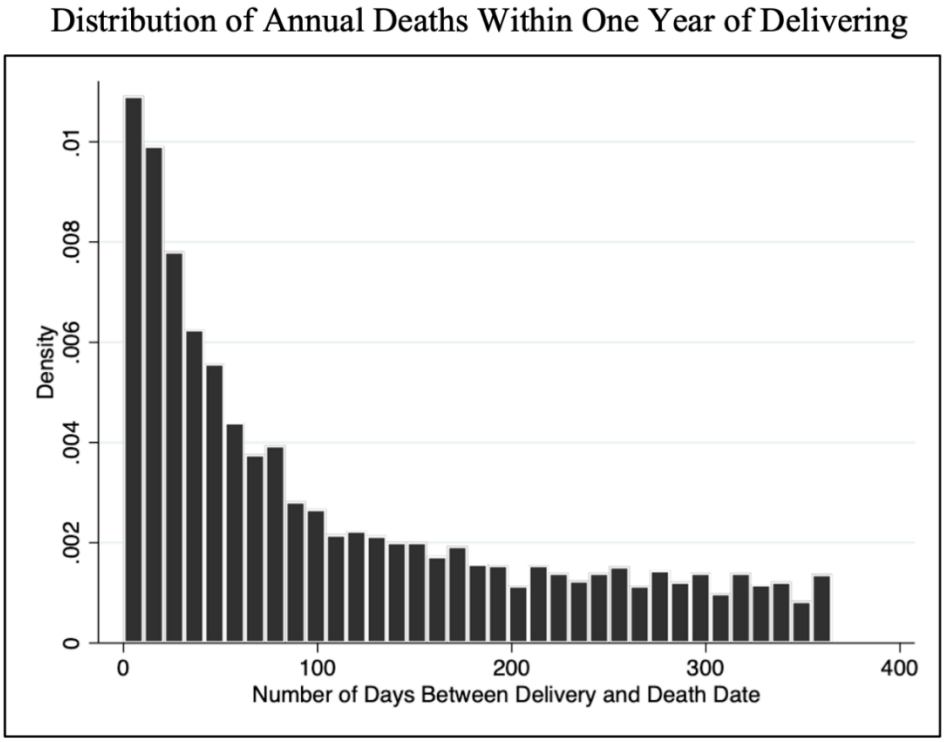
Between metro and nonmetro zip codes, deaths within one year of delivery were consistently more prevalent in metro communities (annual average 0.40% compared to 0.26% of all deliveries; Figure 13).

FIGURE 13: TRENDS IN DEATH WITHIN ONE YEAR OF DELIVERY BY RURAL AND URBAN ZIP CODE OF RESIDENCE AT THE TIME OF DELIVERY. PRESENTED AS THE PERCENT OF DEATHS OUT OF TOTAL DELIVERIES PER YEAR.



Most deaths occurred between 0 and 100 days of delivery, with a high concentration in the weeks immediately following delivery (Figure 14). The effect of a maternity unit-only closure was not statistically significant. Still, closure generally was associated with a 148% increase in the odds of death, and delivery in a zip code associated with a maternity unit closure was associated with a 152% increase in the odds of dying within one year of delivery (Table 17). In the all closures model, white women had the lowest predicted probability of mortality. In the hospital closure model, American Indians and Alaskan Natives have the greatest average probability of mortality after delivery (0.66%), followed by Black (0.40%) and white populations (0.28%) (Table 18).

FIGURE 14: DISTRIBUTION OF DEATHS PER DAY WITHIN ONE YEAR OF DELIVERY.



Discussion

The significant relationships between delivery post-maternity unit closure and travel time and the significance of post-hospital closure and death within a year of delivery present an interesting question and indicate that the type of closure (hospital or maternity unit only) may affect communities differently. One hypothesis is that the presence of a hospital, even if it does not have a maternity care unit anymore, may be able to handle obstetric-related emergencies, preventing death. In contrast, a community without any hospital services, including maternity care, presents a riskier situation. In the case of travel time, the closure of the maternity care unit may result in further travel because of the relocation of providers. In contrast, during a complete closure, some non-hospital services may still be provided in the community, or the maternity services at the hospital may have been duplicative and not disrupted by the closure. These

hypotheses need further research but may indicate a more nuanced picture of the impact of closures in rural communities.

In the travel time models, non-white race was not positively associated with an increase in travel time compared to white Medicaid beneficiaries on its own. However, rurality was increasingly associated with longer travel times, and race and rurality jointly were positively associated in some cases. In particular, Black metropolitan beneficiaries in high commuting zip codes, Black small town core beneficiaries, and rural American Indian and Alaska Native beneficiaries had longer travel times than their white, metropolitan peers. This finding, combined with the finding of increased odds of death for Black, American Indian and Alaska Native beneficiaries highlights the highly regional and complex nature of the maternity care system. In a study of North Carolina deliveries after closure, researchers also identified highly regionalized patterns of care, which complicates the implementation of effective interventions and policies (27).

Other literature has explored whether closure influenced prenatal and postpartum services. These services proved challenging to identify given global codes used in Medicaid billing, so we were not able to explore these measures in this study. Data sources from health systems or single-payer systems may be more equipped to answer questions related to visit utilization and changes in utilization following a closure.

Limitations

ICD-10 was implemented during the study period. While we attempted to crosswalk codes for all variables using both ICD-9 and ICD-10 lists, some differences were identified, and results with respect to severe maternal morbidity revealed unusual trends over time (65). The models also used data with many missing values, which can bias model results. For example,

because of the way travel time is calculated, missing values are not missing at random. Certain zip code combinations were unable to be included because either the geocoding software was unable to determine a valid driving path or the delivery zip code and beneficiary zip code were the same indicating no travel was required, impacting the model estimates' size and significance. The definition of mortality likely overcounts the number of deaths in the postpartum period because the reason for death was not reviewed on a case-by-case basis (65).

Because this study uses Medicaid data from only one state, results are not generalizable across the US. Results may be impacted by policies and practices specific to North Carolina norms and regulations. Within the Medicaid population, churning in and out of coverage is common. As a non-expansion state, North Carolina currently restricts coverage for beneficiaries covered by the Medicaid for Pregnant Women program (available to women over 42% of the federal poverty line) to 60 days postpartum (67). In the dataset, beneficiaries with Medicaid for Pregnant Women accounts for 35% of all Medicaid deliveries in North Carolina during the study period and slightly less than 50% of the deliveries in the Aim 3 models. Because of this, maternal mortality may be undercounted because deaths for individuals without Medicaid coverage at the time will not show up in claims. Plan Type was a matching criterion to mitigate issues related to this restriction. Finally, this study only captures diagnoses and procedures billed to the Medicaid program. It does not count services individuals paid for out of pocket, those that were not covered, or those that were received but not billed for by the provider of services.

Policy Implications and Future Research

Findings from this study highlight the complexity of identifying maternity care and maternal health outcomes in administrative claims data. Consistently and accurately coded data is required to identify challenges and track the progress of interventions and programs to

improve maternal health. The models also suggest that race and rurality jointly impact maternal health outcomes, presenting a more nuanced picture of need and vulnerability within the maternity care system than previous research. These findings offer insight to potential community and health system strategies to mitigate the negative effects of closures. For example, targeting strategies to communities with long travel distances, such as very rural American Indian and Alaskan Natives, to reduce racial disparities in maternal health, providing obstetrics readiness support for hospitals with recently closed maternity units, and improving referral networks and transportation for hospital deliveries for individuals without a hospital in their community may complement trends identified in this study. Further research on the effects of closure by insurance type, and by more specific race and ethnicity categories is needed to better understand potential disparities in maternal outcomes following a closure. Additionally, higher quality data using consistent coding practices across billing providers and tested and validated maternal health indicator and outcome measures are needed to fully assess trends over time and the impact of policy or practice-related interventions. Finally, analyses with data from across the US are required to better understand drivers of the maternal health crisis nationally.

STUDY CONCLUSIONS

Integrated Findings

Travel time to appointments was an important issue for women who participated in quantitative interviews and the primary difference in experience between rural only deliveries and closure deliveries. These issues were especially prominent for individuals with other children, pets, or other scenarios where frequent travel is required for family and friends to and from residence to the location of delivery. Quantitative Aims also found individuals who live in communities affect by hospital-based maternity unit closures traveled farther to their delivery location. Increases in travel time to delivery location were associated with an increase in predicted probability of severe maternal morbidity. American Indian and Alaskan Native people living in very rural communities travel on average 20 additional minutes following closure compared to white, metropolitan deliveries.

Certified nurse midwives were negatively predictive of severe maternal morbidity and highly desired by the women interviewed. Women found the support of a midwife or doula during delivery was beneficial emotionally and the quantitative results support midwives are also beneficial for clinical outcomes. Other workforce considerations include the need to train hospital staff in emergency obstetric services. Interviewed women reported feeling safe knowing an emergency room was nearby to handle emergency situations. In the case of closures, the probability of maternal mortality increased after a maternity unit closed but the hospital remained open. A potential explanation for this is that maternity unit closure communities are

unprepared to handle obstetric emergencies once people are discharged and sent home. This notion is reinforced by the increase in travel time following maternity unit closures.

Limitations

This study has several limitations, many of which are due to data availability. First, the quantitative findings are based on North Carolina Medicaid administrative claims data. This restricts the generalizability of findings as other states (e.g., states with other policies and programs like Medicaid Expansion) and individuals with other types of insurance will likely see different results. Since we used administrative claims without accompanying clinical records, we were restricted in understanding an individual's maternity care by the services billed for Medicaid reimbursement on their behalf. Further, many services are billed in bundles. To the extent possible, we categorized variables as granularly as we could. Native American women may have been underrepresented in our sample because their claims may be in the Indian Health Service claims instead of the Medicaid claims files.

Policy Implications and Future Research

Closure of maternity units in rural hospitals has consequences for when, how, and where rural women access maternity care. Understanding the downstream and amassing effects of maternity care system changes has important implications for insurance and reimbursement policy, rural hospital operations, and policies and interventions to reduce rising maternal morbidity and mortality rates, and health disparities. This study can inform a system dynamics simulation model to understand the implications of policy and hospital operations decisions.

APPENDIX 1: SYSTEM SUPPORT MAPPING INTERVIEW GUIDE

System Support Mapping Activity

The purpose of this exercise is to identify areas of improvement for pregnant women in North Carolina.

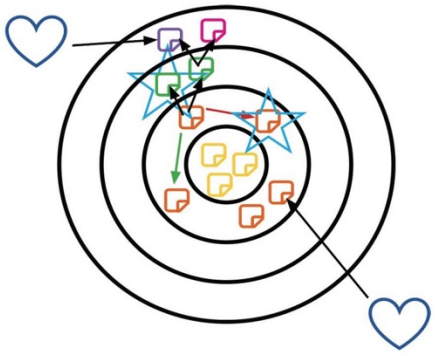
The Purpose

System Support Mapping is a tool to organize key system features to identify areas of need and common experiences in a structured manner. In this case, we are interested in exploring commonalities among pregnant women as they seek care across the maternity care system.

The Process

During a 45-minute video call, you will think about your experience seeking care during your most recent pregnancy. The steps of the process are:

1. Choose 3-5 words or phrases that describe your experience getting maternal care
2. Identify places where you received care
3. Reflect on the connections between places
4. Think about what services you received at those places
5. Note barriers and facilitators you experienced getting services you needed
6. List up to five changes or wishes that would have improved your experience
7. Reflect on your map and identify pieces any "star supports"

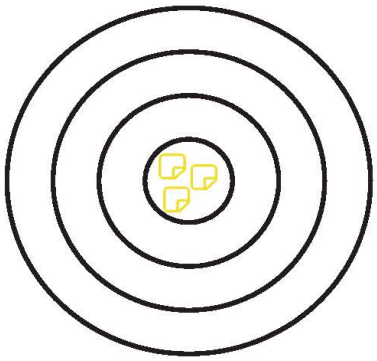


What is maternal care?

Maternal care is anything you need to stay happy and healthy while pregnant and through the postpartum period. The maternal care 'system' detail where and how you receive maternal care - including healthcare providers, family, friends, coworkers, or other sources of support.

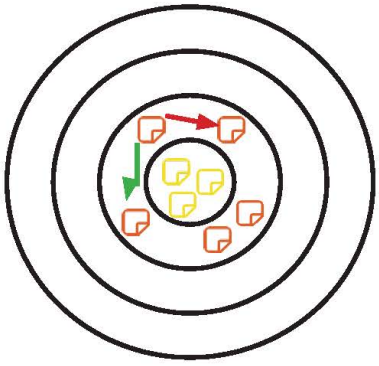
Step 1. Choose 3-5 words or phrases that best describe your experience with maternal care - these words can include the good, bad, ugly, and lovely.

Write those words or phrases on yellow sticky notes and place them in the center of the smallest circle.



Step 2. Identify where you received maternal care. This might include where you received your prenatal checkups, where you delivered your baby, or your new mom support group. Think broadly.

Write these items on orange sticky notes and place them in the second ring of the circle.

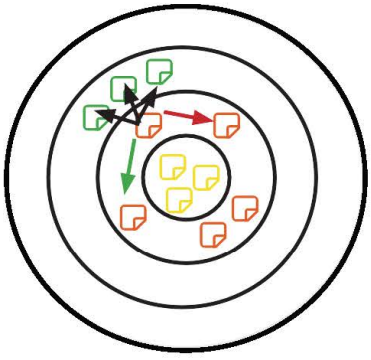


Step 3. Think about the connections between those places. Connections could be relationships or referrals from a healthcare provider.

Use a green marker to draw an arrow connecting places if it was a positive experience and a red arrow if the connection was difficult or negative.

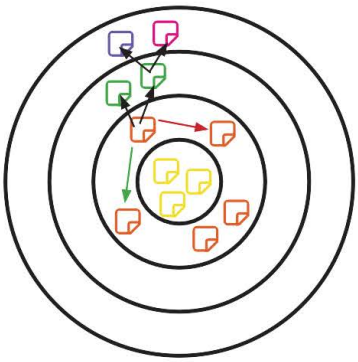
Step 4. For each place you've written down, think about the services you received there. If you received the same service in multiple places, just write it once.

Write those services on green sticky notes and place them in the third ring of the circle. Draw arrows from places to the services you received using a black



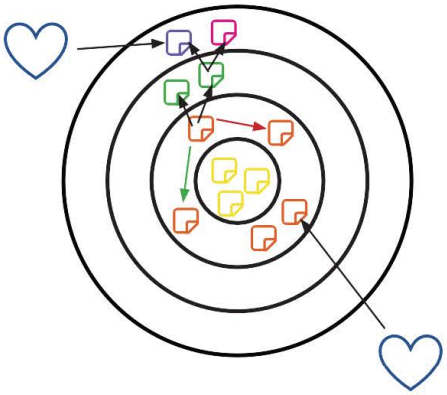
Step 5. Think about barriers and facilitators you experienced to receiving each service. Examples include long travel times, difficult appointment scheduling, or insurance preventing you from accessing care. On the other hand, perhaps you were helped by generous insurance coverage, extended provider hours, or family/friends.

Write facilitators on pink sticky notes, and write barriers on purple sticky notes. Place them in the fourth ring of the circle.



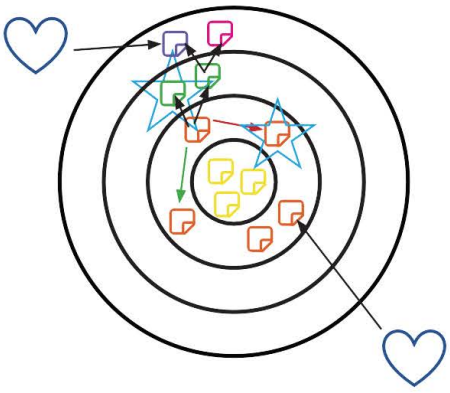
Step 6. Think about what wishes you have for maternal care - this could be changes to existing places or services, places you did not use, or services you did not receive.

Write each wish on a heart and place it on the template. If they are related to an existing place or service, connect the hearts to those places or services with arrows.

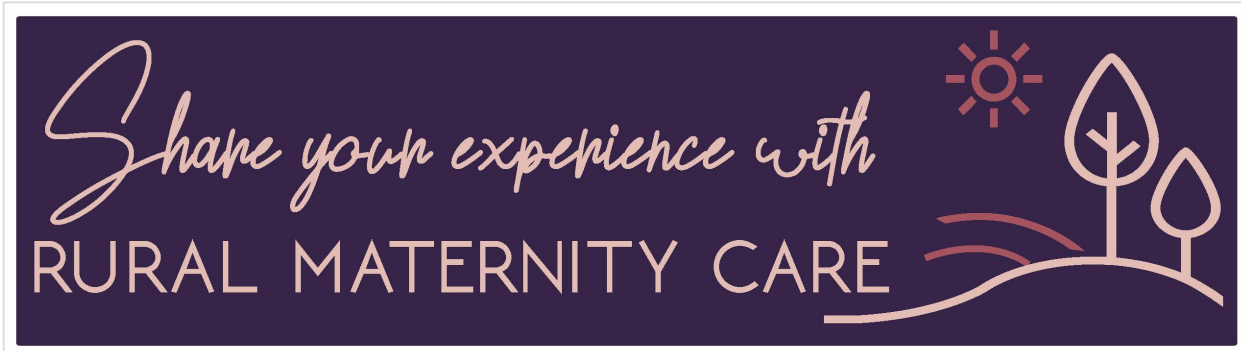


Step 7. Reflect on the moments you were thankful for ("star supports") on your map, or add moments you were thankful for.

Place a star around the sticky note or write a new item inside a star.



APPENDIX 2: EXAMPLE OF RECRUITMENT FLYER



WE WANT TO BETTER UNDERSTAND HOW WOMEN NAVIGATE RURAL MATERNITY CARE

Research participants will be asked to participate in a 45-minute virtual interview describing their experience with maternity care. To structure the interview, we will use a mapping process called system support mapping.

ARE YOU ELIGIBLE?

- ✓ Delivered while living in a rural community
- ✓ Delivered between 2011 & 2019
- ✓ At least 18 years old at the time of delivery
- ✓ English-speaking

PARTICIPANTS RECEIVE A $20 AMAZON OR WALMART EGIFT CARD

TO PARTICIPATE

1. Check if your residential zip code is rural here
2. Complete the eligibility screener using the QR code or click here

Have Questions?

Contact the study team
Kathleen Knocke
919-391-8973
kathleenknocke@unc.edu

This study (IRB Study# 20-3437) has been reviewed by the UNC Institutional Board and determined to be exempt from federal human subjects research regulations. If you have any questions or concerns, you may contact the IRB at 919-966-3113 or by email at IRB_subjects@unc.edu.

R★MAPS
RURAL MATERNITY CARE EXPERIENCE STUDY

APPENDIX 3: PARTICIPATION SCREENER

Participation Screener

Start of Block: Block 1

Q1

This eligibility screener is expected to take less than 2 minutes to complete.

Research participants will be asked to participate in a 45-minute virtual interview describing their experience with rural maternity care. To structure the interview, we will use a mapping process call system support mapping.

Zip code information will be used to identify whether you lived in a rural community or rural community that experienced a maternity unit closure at the time of delivery. The list of rural zip codes used in this study can be found using the link below. Demographic data will be used to increase study diversity. Contact information will be used to schedule an interview, if selected.

Verify your residential zip code is considered rural for this study:
North Carolina Rural Zip Codes

Please answer the following questions to help the study team determine eligibility.

End of Block: Block 1

Start of Block: Block 2

Q12 Please enter the month and year (MM/YYYY) of each delivery between 2011 and 2019. Complete as many boxes as needed and leave extra boxes blank.

- ○ First Child _____
- ○ Second Child _____
- ○ Third Child _____
- ○ Fourth Child _____
- ○ Fifth Child _____

End of Block: Block 2

Start of Block: Block 3

Carry Forward Entered Choices - Entered Text from "Please enter the month and year (MM/YYYY) of each delivery between 2011 and 2019. Complete as many boxes as needed and leave extra boxes blank. "

Q13 List your zip code of residence for each delivery.

- First Child _____
- Second Child _____
- Third Child _____
- Fourth Child _____
- Fifth Child _____

Q15 Were you at least 18 years old at the time of your first delivery?

- Yes
- No

Skip To: End of Block If Were you at least 18 years old at the time of your first delivery? = Yes

Carry Forward Entered Choices - Entered Text from "List your zip code of residence for each delivery. "

Q6 Please select your gender.

- [ ] Woman
- [ ] Man
- [ ] Transgender
- [ ] Non-binary / non-conforming
- [ ] Prefer not to respond

Q10 Select all insurance types had at the time of any listed deliveries.

Example: If Medicaid covered the first delivery and an employer-sponsored plan covered the second delivery, select both Medicaid and employer-sponsored. If covered by more than one insurer for the same delivery, select both.

- [ ] Medicaid
- [ ] Employer-sponsored
- [ ] Medicare
- [ ] No insurance
- [ ] Prefer not to respond
- [ ] Other _____

Page Break

Q7 Please enter your contact information.

Contact information will not be share and will only used to schedule the interview.

- ○ Email _____
- ○ Phone Number _____

Q17 Preferred method of contact.

- ☐ Email
- ☐ Call
- ☐ Text

Q11 Will you have access to a laptop, tablet, or other screen during the interview?

- ○ Yes
- ○ No
- ○ Maybe

End of Block: Default Question Block

APPENDIX 4: LIST OF NORTH CAROLINA CLOSURES OVER THE STUDY PERIOD

Month/Year	Name	Closure Type	NPI
June/2014	Vidant Pungo Hospital	Hospital with Maternity Unit	1346205978
Missing/2015	Charles A. Cannon, Jr. Memorial Hospital	Maternity Unit	1225088255
March/2015	Transylvania Regional Hospital	Maternity Unit	1376613703
May/2015	Yadkin Valley Community Hospital	Hospital with Maternity Unit	1003134883
Oct/2015	Novant Health Franklin Medical Center	Hospital with Maternity Unit	1801866140
March/2017	Davie Medical Center – Mocksville	Hospital with Maternity Unit	1588793624
July/2017	Angel Medical Center	Maternity Unit	1902059173
Sept/2017	Blue Ridge Regional Hospital	Maternity Unit	1679570840
Nov/2017	Sandhills Regional Med Ctr	Hospital with Maternity Unit	1134194178
Dec/2017	Our Community Hospital (Scotland Neck)	Hospital with Maternity Unit	1790809440
Dec/2018	Cape Fear Valley-Bladen County Hospital	Maternity Unit	1558537282
April/2019	Rutherford Regional Medical Center	Maternity Unit	1245321181
Oct/2019	Martin General Hospital	Maternity Unit	1851362669
Dec/2019	Erlanger Western Carolina Hospital (Murphy Medical Center)	Maternity Unit	1801831102

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