A RETROSPECTIVE COHORT STUDY OF THE EFFECT OF MOBILITY DURING PREGNANCY AND TRAFFIC EXPOSURE ON ADVERSE REPRODUCTIVE OUTCOMES IN WASHINGTON STATE, 1992-2004

BY

SYLVIA R. BROWN, MPH

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ABSTRACT OF THE DISSERTATION

A RETROSPECTIVE COHORT STUDY OF THE EFFECT OF MOBILITY DURING PREGNANCY AND TRAFFIC EXPOSURE ON ADVERSE REPRODUCTIVE OUTCOMES IN WASHINGTON STATE, 1992-2004

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Dissertation Director:
Dr. Daniel Wartenberg

Numerous studies have investigated the association between air pollution and adverse reproductive outcomes. Many estimated exposure at the birth residence. Previous research has indicated that up to 32% of mothers change residency during pregnancy. Failure to account for this mobility may result in exposure misclassification.

We assessed the frequency and characteristics of mobile mothers, the association between mobility and term low birth weight (LBW), preterm delivery (PTD) and small for gestational age (SGA) and the effect of a residency change on the association between these outcomes and traffic exposure, a proxy for air pollution. We used routinely collected time-at-current residency data collected on the Washington State birth certificate since 1989 and state-provided traffic counts

We found that a large proportion (32%) of women in Washington State moved during pregnancy and that almost half of these (45%) moved in the third trimester. Compared to non-movers, movers were younger, less educated, unmarried, on Medicaid and unemployed and moved to neighborhoods that were more urbanized, less residentially stable, and had higher percentages of rental and vacant housing units. We found that, multiparous movers, compared to multiparous non-movers, had elevated odds ratios for LBW, PTD and SGA but that primaparous movers, compared to primaparous non-movers, had smaller odds ratios for these outcomes. Finally we found that the birth residences of LBW, PTD and SGA births, compared to residences without these outcomes, and the birth residences of movers, compared to that of non-movers, were located closer to roadways and had higher weighted traffic exposures. We observed higher adjusted odds ratios for our outcomes of interest for movers compared to non-movers for those living within 750 ft. of a roadway compared to living more than 750 ft. from a roadway but higher adjusted odds ratios for non-movers, compared to movers, for the quintiles of weighted traffic exposure for births within 750 ft. of a major roadway.

It is unclear whether the different effects we observed for movers vs. non-movers are due to residual confounding or exposure misclassification. However, our results do suggest that mobility during pregnancy remains a factor to be considered in similar analyses.

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Finally, I would like to dedicate this work to my 99 year old mother, Dorothy Rabinowitz, who, in her increasing fog of old age, still asks me about my "book"– and now I can tell her, before she passes from this earth, that it is finally finished.

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INTRODUCTION

Identifying ways to decrease the high rates of low birth weight (LBW) and preterm birth (PTD) in the US is a major public health challenge at both the state and national levels. Unfortunately, these rates continue to rise (1). Between 1990 and 2005 alone, the rate of LBW and PTD increased 17% and 20%, respectively. Moreover, the adverse affect of these outcomes influences not only the health of the newborn (2) but also the health of the child later in life (3, 4).

While there are multiple factors known to be associated with LBW, PTD and small for gestational age (SGA), such as maternal age and race, the underlying etiology of these outcomes is not well understood. In studying this issue, some researchers have hypothesized that maternal exposure to air pollution during pregnancy may be causally associated with adverse reproductive outcomes. Over the past decade, multiple studies have been conducted to examine this possible association for LBW (term and preterm)(5-22), SGA (10, 15, 21, 23, 24), and PTD (6, 10, 14, 15, 20, 21, 25, 26). Several studies assigned proximate ambient pollutant concentration measurements to birth residences, often reporting statistically significant associations between carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and particulate matter (PM) and different measures of fetal growth and gestational duration for varying time periods during pregnancy (27). However, some researchers have suggested that these regional air monitoring data do not adequately capture intra-community spatial variation, leading to erroneous results (21, 28, 29). To address this, some have used measures of traffic volume - the primary source of criteria air pollutants in many urban areas – as their measure of exposure to ambient air pollution.

One limitation of many of these studies is that there may be exposure misclassification if the assignment of exposures is based on the birth residence, if the mother changed residence(s) during pregnancy, and if the exposures differ among the homes. Previous research reported that between 12% and 35% of women move during pregnancy.(21, 30-33). Some studies have assumed that exposure misclassification attributable to change in residence during pregnancy would likely be non-differential, biasing the results toward the null. Two studies have addressed this issue directly. (7, 23) Ritz et al. investigated the possible association between PTD and air pollution, specifically PM_{10} and CO, among a cohort of births in Southern California 1989-1993 (26). In a follow-up analysis of the same cases and controls (34) these authors limited subjects to those who did not move during pregnancy (based on the 40% of the subjects who provided residence histories). They reported larger but less precise effect measures for non-movers than the entire study population, consistent with exposure misclassification due to change in residence, although participation bias cannot be ruled out as an explanation. Brauer et al avoided this issue by constructing residential histories for all births in their cohort utilizing British Columbia health plan registry files, hospital discharge record and physician billing records and then assigning exposures to the different maternal residences during pregnancy. (21).

Since the high rate of mobility during pregnancy increases the likelihood of exposure misclassification if a change of residence results in a concomitant change in environmental exposures, we undertook a study to examine this issue using an unusual data source. Nearly 20 years ago, the Washington State Department of Health added a data field called, “time at current residency” (), to its birth certificate. We use this data field in a study of a large cohort of births spanning multiple years to identify whether or not a mother changed residence during her pregnancy and the implications of mobility during pregnancy with respect to birth outcomes. We divided this effort into three parts. First we sought to better describe the predictors of a change in residency during pregnancy. Second, we examined the association of a change in residency with LBW, PTD and SGA. Third, we assessed whether the distance of a mother’s residence to highly trafficked roadways, adjusted for the annual average daily traffic volume (AADT) is associated with adverse birth outcomes (term low birth weight (LBW), spontaneous preterm birth (PTD) or small for gestational age (SGA). We also investigated whether these associations differ for mothers who changed residency during pregnancy as compared with those who were residentially stable. We present the background, methodology and results and discussion of each of these efforts in the chapters that follow.

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MANUSCRIPT 1

A Retrospective Cohort Study of

The Effect of Mobility During Pregnancy and Traffic Exposure

on Adverse Reproductive Outcomes in Washington State, 1992-2004

Part I: An Assessment of the Proportion and Characteristics of Women in Washington State who Changed Residence while Pregnant

May 2009

Sylvia R. Brown, MPH

PhD Candidate

ABSTRACT

In conducting studies of possible associations between environmental exposures and adverse birth outcomes, researchers frequently use residential address at birth to link individual births to specific exposure values. However, depending on the method of exposure ascertainment, a change of residence during pregnancy may result in misclassification of exposure if exposures differ between residences. To understand potential predictors of this source of exposure misclassification, we utilized month and year at current residence routinely collected on Washington State Birth Certificates to examine, across mobility groups, the socio-demographic patterns of mothers of singleton births between 1999 and 2001. We found that 32% of women move during pregnancy and that almost half of these (45%) moved in the third trimester. Considering each sociodemographic characteristic separately, the categories with the largest proportion of subjects who moved during pregnancy were 15-19 years old, African American, unmarried, reported occupation as unemployed or housewives, no formal education beyond high school and Medicaid recipients. We compare neighborhood characteristics of mothers who moved during pregnancy to those who did not. Mothers who moved more likely to be living in neighborhoods that were more urbanized, had higher percentages of rental and vacant housing units, smaller percentages of persons living in the same residence for the previous 5 year period and with a higher percentage of people with at least a high school education compare to the neighborhoods of non-movers. Given the high prevalence of mobility during pregnancy, we conclude

that exposure misclassification could be substantial when changes in residency during pregnancy are not considered in assessing environmental exposures based on birth residence.

INTRODUCTION

Several researchers have investigated possible associations between a variety of environmental exposures and adverse birth outcomes (1-3). In conducting these studies, researchers most often have used residential address at birth to link each birth to specific exposure values even though periods of fetal susceptibility to exogenous agents, typically of 1 to a few weeks, occur at different times prior to delivery, depending on the specific outcome.

A few studies have reported that between 20 and 32% of pregnant women in the US move during pregnancy (4) (5) (6). These studies were small and thereby limited in their ability to ascertain with high precision the association between many maternal characteristics and a change in residency during pregnancy. However, the high prevalence of mobility during pregnancy increases the likelihood of exposure misclassification if a change of residence results in a concomitant change in environmental exposures.

To better understand the predictors of this potential exposure misclassification, this study compares the characteristics of mothers who move during pregnancy (movers) with mothers who are resident at the same location during their entire pregnancy (non-movers) in the population of all resident singleton births in Washington State between 1999-2001 using data routinely collected on the Washington State standard birth certificate. Our goal is to ascertain the prevalence of mobility during pregnancy, to describe the socio-demographic, reproductive and neighborhood-at-delivery characteristics of mothers who move during pregnancy and those who do not, to identify the predictors of mobility in this population, and to examine whether these characteristics vary by the trimester in which a mother moved.

DATA AND METHODS

DATA

We examined all live singleton births born to mothers resident in Washington State over a three year period (1999-2001). We obtained residential mobility information from the time-at-current-residency data field recorded in months and years on the birth certificate. Beginning in 1989, Washington State mothers have been asked to report "How long at Current Residence" in months and years. This question appears alongside other demographic questions, such as telephone number and mailing address. Note that according to the US census, "Migration is commonly defined as moves that cross jurisdictional boundaries (counties in particular), while moves within a jurisdiction are referred to as **residential** mobility." (7) In the absence of detailed knowledge about the moves of mothers who changed residency, we utilize the term mobility to describe maternal change in residency in this paper.

We chose to limit our study to the years 1999-2000 since it temporally corresponds best to the 2000 census while yielding a sufficiently large data set. To facilitate comparisons among movers and non-movers, we identified maternal characteristics, medical risk factors and pregnancy history factors examined in previous maternal mobility studies (4) (5) (6) (8) and in a recent reproductive migration study (9) and extracted these from the birth certificate. These factors include age, education, race, ethnicity, parity, prenatal care, marital status, smoking, insurance coverage, as a proxy for individual income, and maternal occupation (housewife, student, unemployed, or under age 16 since occupation is not captured for these mothers) as a proxy for employment status, maternal medical risk factors (diabetes, hypertension, herpes, bleeding) and prior pregnancy history. Since a change in residency may be due to paternal factors, we would have liked to have included these in our analysis. However, a large number of births - primarily to unmarried women who had not yet filed a paternity affidavit (10) - were missing these data. In order not to exclude these women from our study, we created a variable to indicate whether or not paternal data were missing and utilized this, rather than the actual paternal covariates, in our analysis. Finally, we used the geocoded block group of the birth residence to identify the year 2000 neighborhood characteristics.

METHODS

We first examined differences in individual characteristics between those with time-at-current-residence (mobility data) recorded on the birth certificate versus those missing this information. For each maternal covariate, we calculated the proportion of those missing mobility data. We also calculated, for each group, the proportional distribution of each maternal covariate, including missing values, and then assessed the difference in proportions between the two groups.

Second, for those with mobility data, we determined whether or not a mother moved during pregnancy (mobility status) by ascertaining whether the time-at-current-residence was equal to or greater than the gestational age. This required first an assessment of the validity of recorded gestational age and then a comparison of gestational age to time-at-current-residence. To assess the validity of recorded gestational age, we assumed that birth weight was recorded accurately (11) (12) and then determined whether birth weight, in combination with the calculated gestational age (CGA), which is based on the last menstrual period, conformed to the ranges suggested by Alexander et al. (13) We utilized physician estimate of gestational age (PGA) when the CGA was missing or was found inconsistent with the recorded birth weight. All births less than 20 weeks gestation were excluded from the analysis since they could not be validated using the Alexander birth weight ranges and births greater than 43 weeks were also excluded as unreliable. Gestational ages found consistent with birth weight were converted to days (weeks * 7). Time-at-current-residence was also converted from years and months to days (total months * 365/12). A mother was classified as a "Mover" when the gestational age, in days, was greater then the time-at-current-residency in days; otherwise, a mother was classified as a "Non-mover". The specific trimester when a move occurred was determined by comparing the number of days at current residence to the number of days in each trimester (280/3=93.33 days).

Third, for those with mobility data, we extracted neighborhood characteristics of the birth residence. We obtained neighborhood level data by linking the year 2000 block group number on the birth record to the year 2000 US Census block group data obtained from the Research Package from Geolytics, Inc. Based on previous studies (14-18) we identified nine components of social economic status and utilized the following census data elements to measure each: *income*: median household income, median family income, per capital income; *poverty:* % persons in poverty and % children in poverty, *wealth:* median home value, % households on public assistance % owner occupied housing, median gross rent; *education:* % adults with less than a high school diploma; *unemployment:* % of unemployed persons in the labor force; *crowding: %* people per living in households with >= 1 person per room; *density* : persons per square mile [of land]; *housing*: median age of structure; *population diversity:* % non-white, % Hispanic, % residents < 18: % residents > 64; and, *stability*: % persons age 5 or more in same house for 5 years (stable population). Krieger(19) advocated the use of the block group as the most homogenous level for evaluation of geographic data and health, and has shown that the use of quintiles works well for analyses of this type of data. We therefore computed the quintile distribution for each block group (neighborhood) measure using all births with mobility status and assigned a value of 1 or 0 to each measure to indicate whether it was in the highest quintile or not.

We calculated the distribution of individual and neighborhood variables, including the proportion of missing values, for the entire cohort, for each mobility group (movers vs. non-movers), and for trimester of move. We also calculated the Spearman correlation coefficients among all individual and neighborhood level variables and the unadjusted odds of moving for each dichotomized individual and neighborhood characteristic.

To estimate the independent effect of individual and neighborhood level characteristics adjusted for other covariates, we modeled the odds of mobility (movers vs. non-movers) using unconditional multiple logistic regression. We excluded two measures of wealth - median household income and per capita income - since both were found to be very highly correlated with median family income (r^2=0.94 and 0.85, respectively). We also excluded owner occupied housing since it was inversely correlated with percent of vacant housing (r^2= -1.00). We entered into our model all independent variables found, in our unadjusted analyses, to have had at least a 10% effect on mobility (odds ratios >=1.10 or <=0.90). We limited our final model to those independent variables showing at least a 10% adjusted effect on mobility and whose confidence intervals exclude unity. Our modeling efforts are restricted to those births with complete data on all individual and neighborhood level variables. We identified births eliminated from the modeling effort due to missing values (n=50,947 23.96%) in order to examine the effect of missing data bias on our adjusted results. We took a conservative approach, making no assumptions about whether a missing value was inherently informative. For example, no information on prenatal care may indicate the absence of prenatal care or a failure to record that data item. We did not assume the former, and therefore eliminated these births from our modeling effort. The single exception to this approach, as noted above, was the inclusion of births with missing paternal data since we were able to document the reason for this frequent occurrence.

Our study base was not a sub-sample but rather it consisted of the complete enumeration of singleton Washington State births over a 3 year period. We report 95% confidence levels as an indication of the precision of our results; we do not report p values. All analyses were done using SAS software version 9.1(20)

RESULTS

<u>Presence of Time-at-Current-Residency (Mobility) Data:</u>

There were 228,773 singleton births born in Washington State to Washington state resident mothers between 1999 and 2001. Approximately 5.5% of these births (n=12,529) were missing time-at-current-residency data. Time at current residence was missing even more frequently among mothers who were under age 20, with less than 12 years of schooling, non-white, Hispanic, unmarried, foreign born, receiving Medicaid, smoked during pregnancy, had a previous c-section or a live birth within the last year . The proportion of missing time-at-current-residency data varied by reported county of residence. In 75% (n=29) of the 39 counties in Washington State, the proportion of missing time at current residency data was 5% or less, 15% (n=6) of the counties were missing between 6% and 10% of these data and 2 counties were missing 18% and 13%. Two small counties which accounted for only 1.6% of all births were missing mobility data for 79% of their births.

Mothers with Time-at-current-residence (Mobility) Data

Of the 216,244 births with mobility data, 3% (n=3,614) were excluded due to missing (n=2,415) or out of range (n=53) gestational age or missing (n=731) or out of range (n=415) birth weight. Our analysis thus consisted of 212,630 births. The number of months at current residence ranged from 5 to 504 months, with 62% reporting residency time of 3 years (36 months) or less. A digit preference in reporting at the 12 month time point was observed: 12.48% of the 212,630 women reported a residency time of 12 months, 9.57% reported a residency time of 24 months and 6.92% reported a residency time of 36 months. In addition, a preference in reporting at the 6th month mark was also observed for all except the first year of residence: <1% reported living at their current residence 6 months, 4.13% reported 18 months and 2.64% at 30 months at their current residence.

Approximately 32% (n=67,321) of the 212,630 mothers changed residence during pregnancy (Table 1). Of those who moved, 17% (n=11,290) moved during the 1st trimester, 38% (n=25,626) during the 2nd trimester and 45% (n=30,248) during the 3rd trimester. These proportions were consistent across all three years of the study.

Maternal Characteristics: The distribution of maternal characteristics by mobility status and trimester of move is presented in Table 1. We found at least a 10% difference between mobile and non-mobile mothers in the percent distribution of age, education, marital status, payor status, prenatal care status and parity. For example, 61.6% of mobile mothers were 20-29 years old compared to 47% in the non-mobile group, 39% of mobile mothers versus 22% non-mobile mothers were unmarried, 43.5% of mobile mothers were on Medicaid vs. 26% of non-mobile mothers and 47% of mobile mothers were first time mothers compared to 37% of non-movers. We observed small (<8%) differences between the trimester-specific distributions of maternal characteristics. For example, 33% of first trimester movers were unmarried and 38% received Medicaid. This compares to 41% and 46%, respectively, of third trimester movers.

Neighborhood Characteristics: 2000 Census block group data was obtained for 209,494 births. Mothers resided in 4,799 of the 4825 block groups in Washington State. The median number of births per block group ranged from 1 to 1113, with a median of 35 births per block group. The inter-quartile range was from 23 to 54 births per block group.

The distribution of the neighborhood characteristics of the birth residence, by mobility status and trimester of move, is presented in Table 2. The maximum difference in the proportions between the two groups was 9%. For example, 14% of mobile mothers compared to 23% of non-mobile mothers lived in neighborhoods where the median family income was at least $68,000 and a larger proportion of mobile mothers lived in neighborhoods where more than 56% of the housing units were rental (28% vs. 16%).

Mobility Model:

When modeling the odds of mobility, we restricted our cohort to those births with complete data on all individual and neighborhood level variables (n=161,683). Most of the exclusions were due to missing data for prenatal care (n= 16,494), maternal education (n=14,614) and/or payment source (12,446). However, the proportion of total movers in the modeling cohort (31%) was consistent with that found in the full cohort (32%) and the proportion of trimester-specific movers was also consistent. In the modeling cohort, 17.4% moved during the 1st trimester, 38.2% during the 2nd trimester and 44.4% during the 3rd trimester; compared to 17%, 38.1% and 44.9% in the full cohort.. Approximately, 93% of movers in the modeling cohort changed residence at least 31 days after the start of pregnancy and 96% of non-movers lived at their current residence at least 31 days prior to the start of pregnancy.

The results of our modeling efforts (Table 3) indicate that, adjusted for other covariates, categories for which the odds ratios for moving during pregnancy exceeded 1.10 (a 10% excess) included mothers 15-19 years old [OR=1.19 (1.14 - 1.25)] compared to mothers age 20-29, African American [OR=1.12 (1.05 - 1.19)] compared to White mothers, unmarried mothers [OR=1.27 (1.23 - 1.31)], Medicaid recipients [OR=1.29 (1.24 - 1.33)], first time mothers [OR=1.38 (1.35 - 1.42)] , smokers [OR=1.30 (1.25 - 1.34], housewives [OR=1.16(1.13-1.19)] or unemployed mothers [OR=1.29(1.22-1.36)] compared to those listing other occupations, and mothers for whom less than a year had passed since their last live birth [OR=1.26 (1.14 - 1.40)]. Similarly, the neighborhoods census variables that had odds ratios for moving during pregnancy that were greater than 1.10 included percent of rental housing [OR=1.50 (1.44-1.57)] and percent of vacant housing units [OR=1.20 (1.16-1.25)] and percent urbanized [OR=1.19 (1.15-1.24)]. Categories for which the odds ratios for moving during pregnancy were less than 0.90 (a 10% deficit) included mothers who were age 30 or more, college graduates [OR=0.79(0.76-0.83)] or beyond, Asian [OR=0.84 (0.80-0.89)] or Hispanic race [0.90 (0.86 - 0.94)], born in Washington State [OR=0.84 (0.82 - 0.86)], had private insurance [OR=0.81(0.78-0.83)], started prenatal care during the 1st trimester [OR=0.67 (0.65 - 0.70)], were students or women below age 16 for whom occupation is not captured [OR=0.77 (0.73 - 0.82]. were diabetics [OR=0.90 (0.85-0.96)], and for whom less than 1 year has passed since their last fetal death [OR=0.89 (0.84 - 0.95)]. The birth neighborhood variables that had odds ratios for moving during pregnancy that were less than 0.90 included percent in the same residence for 5 years [OR=0.86 (0.83 - 0.89] and percent of persons without a high school education [OR=0.87 (0.84 - 0.91)].

Results of our trimester-specific modeling efforts are also shown in Table 3. Compared to non-mobile mothers, the adjusted odds ratios of moving during pregnancy vary by trimester for some individual covariates. For example, adjusted for other covariates, the odds ratio for moving anytime during pregnancy for mothers age 15-19, compared to those age 20-24, was 1.14 (1.04-1.25) while the odds ratio for moving during the third trimester was 1.29 (1.22-1.38). For unmarried women, the odds ratios are 1.08 (1.02-1.15) and 1.31(1.26-1.37) for the 1^{st} and 3^{rd} trimesters, respectively. A similar pattern is seen for Medicaid recipients, smokers, housewives, the unemployed and time since last live birth. The odds ratios of moving also decreased in magnitude by trimester for several maternal characteristics. For example, compared to mothers who began prenatal care after the first trimester, the odds ratio of moving during the first trimester for mothers who began prenatal care during the 1st trimester was 0.77 (0.72-0.81) while the odds ratio of moving during the third trimester was 0.68 (0.65-0.71). Also, compared to non-primaparous mothers, the odds ratio of moving during the first trimester for first time mothers was 1.44 (1.37-1.52) while the odds ratio of moving in the third trimester was 1.33 (1.28-1.37). In addition, our trimester specific results indicate that, compared to Whites, the odds ratio of moving in the third trimester for African Americans was 1.22 (1.13-1.32)].

DISCUSSION:

Mobility during pregnancy may affect the accuracy of reproductive outcome studies assessing the possible role of environmental exposures because these studies often use information about environmental exposures assessed at the birth residence as a proxy for environmental exposure during the entire pregnancy. However, if a mother changes residence during pregnancy and the exposures in her new environment are different than in the previous one, then exposure misclassification may result. This is particularly relevant for disorders with susceptibility periods of limited length. In this study we sought to better understand the predictors of this potential exposure misclassification by assessing the proportion of mothers who moved during pregnancy and comparing the socio-demographic, reproductive and neighborhood characteristics of mothers who moved during pregnancy to those who did not.

We found that almost one third of mothers move during pregnancy and more movers (45%) changed residence in the third trimester than either the first or second trimesters. We show in Table 3 that adjusted for other covariates, the odds ratios of moving during pregnancy were at least 1.10 or more for mothers who were young, African American, unmarried, smokers, late starters of prenatal care, first time mothers or mothers who delivered a live birth within the past 12 months, housewives or unemployed, Medicaid recipients, non-diabetic and for mothers moving to neighborhoods which are more urban, less stable, and have high percentages of rental and vacant housing units. When restricted to a single trimester, these odds ratios increased in magnitude from the 1st to 3rd trimesters for many of these characteristics, including age, marital status and Medicaid status, although the odds ratio decreased between the first and third trimester for first time mothers. In addition, compared to whites, only the odds ratio of moving during the third trimester was elevated above unity for African Americans.

Our finding that 32% of mothers moved during pregnancy is consistent with previous US studies on this topic, all of which identified mobility status by the direct collection of maternal residential histories. Early research (4, 5) reported that approximately 20% of US mothers moved during pregnancy, while the one Canadian based study (8) reported that 12% did so. The most contemporary U.S. study by Canfield et al (6) reported that 33% of cases and 31% of controls changed residences during pregnancy. While both the Canfield study and our study ascertained the proportion of mothers who moved in each trimester, a comparison of the two is inappropriate due to the different methods used to determine the proportions. Mothers who moved during pregnancy could be counted one time only in our study; however, in the Canfield study, a woman who changed residence multiple times was included in the numerator for each trimester when a move occurred (6).

The associations we found between selected maternal characteristics, such as age, race, education, parity, prenatal care, employment status, and mobility during pregnancy were also consistent with patterns identified in previous research. For example, the four previous studies indicate that younger mothers more frequently move during pregnancy and those studies which examined parity (4) (6) (8) also identified an association between first time mothers and mobility during pregnancy. However, the patterns observed in previous studies were not always statistically significant and authors were appropriately cautious in their conclusions about them. Our study, which was substantially larger, found these characteristics to be important predictors of mobility during pregnancy.

Our results indicate that mobility patterns for pregnant women in Washington state are similar to but not entirely consistent with that of the general population. Differences exist with respect to race and education. According to national data (21) statistically significant ($p<.05$) adjusted predictors of mobility for the general population aged 18 and older are: younger age, education beyond high school, unemployment, being a welfare recipient, being unmarried, living below poverty, receiving welfare, living in rental housing, moving from non-metropolitan areas, being non-Black and having no children under 18. In our population, mobile mothers were also more likely to be younger, unmarried, with no children, Medicaid recipients and unemployed and to move to areas with greater proportions of rental housing. However, unlike the general US population model, in our population model Black mobile mothers and mobile mothers with less than nine years education had adjusted odds ratios elevated above unity.

Our finding, that almost one third of mothers change residence during pregnancy, highlights the considerable potential for misclassification of exposure based on birth residence. The magnitude and direction of that misclassification and its effect on study findings will vary according to a confluence of multiple factors: the timing of the change in residence and its relationship to the susceptibility period for the outcome of interest, the direction of the move (to vs. from higher exposure area), the method of exposure ascertainment, and the distribution of exposure misclassification among the comparison groups. For example, fetal abnormalities are most likely to occur in the first trimester (4); therefore if a mother changes residence late in the first trimester or during the second or third trimesters, the exposure assessed at the birth residence would likely be misclassified. Conversely, fetal growth is greatest in the 3rd trimester (22); therefore a move during the first and second trimesters may not result in exposure misclassification while a move during the third trimester would likely do so. The magnitude of the exposure misclassification also will be affected by the direction of the move: a move from an exposed location to a less exposed location would likely result in underreporting of exposure while a move in the opposite direction would result in over-reporting of exposure. All these exposure misclassification scenarios are contingent upon the method of obtaining the exposure metric. A move within the geographic area at which exposure is ascertained, such as the census tract or block group, would not result in exposure misclassification while a move to a different geographic area will likely do so. Conversely, if exposure is ascertained based on the actual distance from the birth residence to a point source or roadway, then exposure misclassification will most likely occur and could be substantial, depending on the actual movement pattern(23). Finally, the effect of exposure misclassification on effect estimates will vary according to whether the misclassification is differential or non-differential. If exposure misclassification is approximately equally distributed among all study subjects (non-differential), and if the exposure is analyzed dichotomously then the misclassification will likely bias the results toward the null. However, if the changes are not equally distributed among study subjects, or if exposure is not a dichotomous metric, then the bias could be in either direction, could differ in magnitude, or might even result in spurious findings (24, 25).

Our findings also may be relevant for research in social epidemiology and other disciplines, such as geography. There is a growing body of literature which explores the relationship between neighborhoods and health(26) (27) and some of these studies utilize address at birth to ascertain neighborhood characteristics for assessing the determinants of reproductive health. For example, one study found an association between low birth weight and census tract income (15) and another between low birth weight and racial segregation(28). If mothers move across the geographic unit used to define neighborhood, such as census tract or block group, then misclassification of neighborhood characteristics may result. Hence, our finding that 32% of women move during pregnancy may directly impact these studies as well.

One strength of our study is that it is much larger than previous studies on this topic. We were able to identify mobility status for 95% of our population without incurring additional data collection costs and without relying on information obtained at lengthy intervals beyond delivery. We were able to assess with good precision the association between mobility during pregnancy and more than 50 individual and neighborhood characteristics, to differentiate among multiple levels of age and education and race and to identify differences in the characteristics of mothers who moved at different time periods in pregnancy.

Our study also has several limitations. First, we utilized the time-at-current-residency field on the Washington State birth certificate, in combination with gestational age, to determine mobility status, our outcome of interest. While misreporting of gestational age could bias our results, we attempted to limit this by insuring that the birth weight/fetal age combination was consistent with parameters identified by Alexander et al (13). The mobility status of only 2% of all births would be affected if gestational age were misreported by 1-2 weeks.

Misreporting of time-at-current residence is the second source of bias affecting outcome ascertainment. The time at current residency was added to the Washington State standardized birth certificate in 1989. Mothers record their responses in months and years. We found no publications which utilize these data; nor did we find any independent data to support the accuracy of maternal responses to this question. We also observed, as noted by Washington State in the documentation that accompanied the birth certificate data (10), digit preference in reporting residency time, with clustered reporting around 6 and 12 months. The proportion of births that may have been misclassified, however, is expected to be very small and thus bias our results only minimally.

A second limitation of our study was the use of administrative data collected for other purposes. We are confident in the internal consistency of the Washington State birth certificate data. The software utilized by the hospitals to enter birth certificate data has on-line edits to validate various data elements, such as mother's age. In addition, Washington State personnel utilize numerous software programs to check for consistency between data items, such as maternal age and parity, to look for outliers, and to examine 3 year trends for all items. Changes are made wherever possible and queries are made back to the reporting hospital/facility when necessary. Washington State personnel examine the birth certificate data both quarterly and yearly (29). We also identified several research studies which assessed the validity and reliability of some of the data elements on the Washington State Birth certificate (10)– specifically birth weight, birth order and maternal smoking (30), maternal diagnoses and procedures (31) (32) (33) maternal pre-existing medical conditions (34), complications of pregnancy and prenatal visits(33). Overall, except for birth weight, these studies suggest an underreporting of these factors. To our knowledge, the validity of many other factors found on the Washington States birth certificate has not been evaluated in detail. A systematic underreporting of residence time or the maternal covariates could bias our results in either direction.

Missing data may also have biased our results. While only 5.5% of mothers are missing time at current residency data, these data are not missing at random. Disproportionately high (>9%) numbers of mothers under age 20, with less than 9 years of schooling, Native Americans, Hispanics, unmarried, Medicaid recipients, students or unemployed, and those missing paternal data were excluded from the study due to missing time at current residency data. Moreover, the amount of missing covariate data was large. We excluded almost 23% of our births (n=47,811) from our modeling process due to missing data. This increased the representation in our models of mothers who are White and who began prenatal care in the first trimester by 7% and 5% respectively. This also reduced the number of mothers with missing paternity data by approximately 7%. Changes in the distribution for other covariates varied between <1% to 3%. However, the proportion of movers remained approximately the same (31%) after the exclusions and our multivariate results are consistent with our bivariate results which did not exclude these mothers. Given the large size of our cohort and the small differences in the distributions between those with and without maternal covariate data, it is likely that any errors incurred would modify the magnitude but not direction of our point estimates.

Using the 2000 Census data to provide neighborhood level data may also have resulted in additional error. These data are most accurate at the time of data collection (April 2000). By limiting our analysis to one year before, the year of, and one year after the 2000 Census, we attempted to minimize the bias associated with changes in neighborhood characteristics during the three year study period.

Finally, our study is limited by the absence of information on why mothers moved during pregnancy, the geographic location from which these mothers moved, how often a mother moved and how long the mother lived at the prior location(s). We do know that most people move short distances (35) and the primary reason for these moves is housing related (36), although these patterns are not specific to pregnant women. We also know that in the western region of the US, 60% of all females who move remain within the same county of residence and an additional 19% remain within the same state but not within the same county (36). A prior US study of mobility during pregnancy found that 70%(5) moved within the same county but no studies have ascertained the reason for moving. It is possible that reasons for moving and/or the location and duration at the prior residency would modify our results in either direction. While we treated mobility as a single construct, the predictors of moving during pregnancy may in fact be different for mothers who chose to move, possibly to attain better access to care or increased kinship support, compared to mothers who are forced to move, perhaps as the result of financial stress or pending eviction.

To our knowledge, ours is the first study to ascertain mobility status during pregnancy using data routinely captured on the birth certificate. Our study confirms that a large proportion of mothers change residency during pregnancy and therefore the potential for exposure misclassification is considerable. Furthermore, our study provides insight into the differences between movers and non-movers and between movers at different trimesters. Our results raise a myriad of interesting questions we were not able to address: Why do mothers move during pregnancy? Why are the odds of moving greater among first time mothers? How far do mothers move? What is the direction of mobility vis-à-vis actual or perceived environmental exposures? Are mobile mothers healthier? Do they seek better access to care? Or is the availability of housing the prime motivating factor? Answers to these questions will help identify whether exposure misclassification based on mobility during pregnancy is differential or non-differential. Additional investigations are needed to answer these questions and address the limitations of our study.

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TABLE 1: MATERNAL CHARACTERISTICS: % DISTRIBUTION BY MOBILITY STATUS

			MOVERS			
	TOTAL	**DID NOT MOVE**	**TOTAL**	**1ST TRIMESTER**	**2ND TRIMESTER**	**3RD TRIMESTER**
Population	N=212,630 (100.00%)	N=145,309 68.34%	N=67,321 31.66%	11,447 5.38% [17.00%]	25,626 12.05% [38.07%]	30,248 14.23% [44.93%]
Age						
< 15	0.14	0.13	0.16	0.18	0.13	0.19
15-19	9.76	7.17	15.35	13.23	14.81	16.62
20-29	51.85	47.32	61.62	62.38	62.71	60.41
30-34	24.04	27.98	15.53	16.59	15.17	15.43
35-39	11.66	14.22	6.12	6.38	5.98	6.13
40+	2.53	3.15	1.19	1.20	1.19	1.18
Education						
0-8	4.46	3.93	5.61	5.36	5.18	6.07
9-11	11.39	9.30	15.92	13.96	15.29	17.18
HS Diploma / GED	28.61	26.52	33.14	32.94	33.91	32.57
Some College	14.67	17.07	9.51	10.64	9.78	8.85
College Degree	23.82	24.63	22.10	22.65	22.61	21.45
Post Graduate	10.05	11.77	6.32	7.53	6.22	5.95
Race						
White	69.47	70.81	66.57	67.55	67.89	65.09
Black	3.98	3.40	5.23	4.33	4.95	5.82
Asian	8.20	8.65	7.23	7.75	6.97	7.26
Native American /Alaskan Native	2.28	2.11	2.65	2.30	2.61	2.81
Hispanic Race	12.19	10.94	14.88	14.75	14.01	15.67
Other White	0.07	0.07	0.07	0.06	0.09	0.05
Ethnicity: Hispanic	13.69	12.33	16.61	16.57	15.82	17.29
Marital Status: Not Married	27.49	22.30	38.71	33.48	38.39	40.96
Place of Birth						
Washington State	40.21	40.87	38.77	37.00	39.76	38.60
Not US Born	21.09	20.65	22.03	23.13	20.88	22.60
Payor						
Medicaid	31.21	25.76	42.99	38.05	42.08	45.62
Private Insurance	33.60	38.34	23.38	26.19	23.85	21.91
Prenatal Care :Began 1st Trimester	77.16	80.33	70.32	74.55	70.28	68.76
Parity: First Birth	40.36	37.32	46.91	47.25	47.77	46.06
Smoked Cigarettes	12.69	10.45	17.53	14.87	17.74	18.36
Occupation						
Housewife	27.82	27.15	29.27	28.37	28.35	30.38
Student or Under 16	5.21	4.53	6.69	6.10	6.36	7.20
Unemployed	4.01	3.26	5.62	5.10	5.51	5.91
Missing Paternal Information	24.64	22.03	30.27	26.07	29.76	32.28
Maternal Medical Risks						
Has at least 1 medical risk	53.07	53.31	52.55	52.08	52.17	53.04
Previous C-Section	1.56	1.52	1.64	1.31	1.63	1.77
Previous Preterm Birth	1.23	1.26	1.18	1.18	1.12	1.24
Diabetes	3.58	3.86	2.98	2.95	2.97	2.99
Hypertension	5.86	5.97	5.63	5.62	5.75	5.54
Herpes	2.65	2.68	2.59	2.66	2.65	2.51
Bleeding	1.42	1.51	1.23	1.15	1.21	1.27
< 1 year since last live birth	1.09	0.97	1.33	1.25	1.32	1.38
< 1year since last fetal death	2.89	3.09	2.45	2.59	2.39	2.43

TABLE 2: NEIGHBORHOOD CHARACTERISTICS OF BIRTH RESIDENCE: PERCENT DISTRIBUTION IN TOP QUINTILE BY MOBILITY STATUS

	CUTOFF	DID NOT	------- MOVED DURING PREGNANCY -------			
	Top Quintile	**MOVE**	**ALL Movers**	**1st Trimester**	**2nd Trimester**	**3rd Trimester**
Study Population		**143,299**	**66,195**	11,290	25,230	29,675
-- INCOME --						
Median Family Income	$67,969	22.62	14.24	15.08	14.32	13.84
Median Household Income	$61,679	22.68	14.16	15.12	14.17	13.79
Per Capita Income	$26,896	22.29	15.01	15.99	14.82	14.80
-- WEALTH & POVERTY --						
Median Housing Unit Gross Rent	$899	22.37	14.77	15.78	14.82	14.34
Median Value of Housing Unit	$207,100	22.15	15.29	16.22	15.16	15.04
% Households Public Assistance	7.47	17.62	25.09	23.20	25.05	25.83
% Children in Poverty	25.69	17.61	25.05	23.38	24.67	26.01
% People in Poverty	18.50	17.36	25.45	23.23	25.05	26.64
-- HOUSING --						
Median Year Housing Built	1985	19.31	18.09	18.78	18.08	17.84
% Renter Occupied Housing	56.41	16.37	27.81	27.85	27.97	27.65
% Owner Occupied Housing	97.69	21.69	16.15	16.77	15.95	16.09
% Vacant Housing Units	8.33	18.01	24.17	23.47	24.11	24.48
% w/o Complete Plumbing	1.24	19.87	20.27	19.51	19.85	20.91
-- CROWDING & DENSITY --						
Persons per Room	0.53	17.88	24.34	23.76	23.68	25.13
Population Density/ Square Mile	6330	19.18	21.76	22.08	21.92	21.50
Persons per Housing Unit	2.95	20.85	18.07	18.06	17.63	18.44
% Urban (dichotomized)	100.00	78.76	82.67	82.64	83.18	82.24
-- STABILITY --						
% Pop in Same House 5 years	59.69	22.10	15.35	15.13	15.28	15.49
-- DIVERSITY --						
% Employable ages 16+	97.26	21.82	16.02	16.78	16.05	15.70
% Employed ages 16+	71.06	21.33	16.78	17.88	17.12	16.07
% With less than HS education	21.33	18.52	23.15	21.73	22.39	24.34
% Children	33.06	20.08	19.73	19.01	19.29	20.37
% White	92.48	21.37	16.80	17.27	16.75	16.66
% Foreign Born	18.00	19.19	21.69	21.43	21.44	22.01
% Hispanic	11.94	18.08	24.08	23.05	23.21	25.22
% Females	53.10	19.42	21.23	21.00	21.40	21.17
% Seniors	14.61	19.79	20.41	19.85	20.53	20.52
% Single Female HH with Children	10.96	17.54	25.28	24.46	25.18	25.68

TABLE 3: ADJUSTED ODDS OF 10% OR GREATER AND 95% CONFIDENCE LIMITS FOR MOVING DURING PREGNANCY

	ALL	1st Trimester	2nd Trimester	3rd Trimester
Total Moved	50,649	8,827	19,329	22,493
Total Did Not Move	111,034	111,034	111,034	111,034
------ INDIVIDUAL CHARACTERISTICS ------				
Age				
< 15	0.77 (0.57-1.03)*	0.80 (0.44-1.44)*	0.72 (0.48-1.10)*	0.84 (0.58-1.21)*
15-19	1.19 (1.14-1.25)	1.14 (1.04-1.25)	1.11 (1.04-1.19)	1.29 (1.22-1.38)
20-29	1.00	1.00	1.00	1.00
30-34	0.56 (0.54-0.58)	0.55 (0.52-0.59)	0.54 (0.51-0.56)	0.58 (0.55-0.60)
35-39	0.44 (0.42-0.46)	0.44 (0.40-0.49)	0.42 (0.40-0.45)	0.46 (0.44-0.49)
40+	0.38 (0.35-0.42)	0.39 (0.32-0.47)	0.37 (0.32-0.43)	0.39 (0.34-0.44)
Education				
0-8	1.02 (0.95-1.08)*	1.02 (0.91-1.15)*	0.97 (0.90-1.06)*	1.06 (0.98-1.14)
9-11	0.99 (0.95-1.03)*	0.98 (0.91-1.06)*	0.94 (0.89-0.99)	1.04 (0.99-1.09)*
HS Diploma / GED	1.00	1.00	1.00	1.00
Some College	0.95 (0.92-0.98)	0.93 (0.87-0.98)	0.95 (0.91-0.99)	0.96 (0.92-1.00)*
College Degree	0.79 (0.76-0.83)	0.79 (0.73-0.85)	0.79 (0.74-0.83)	0.79 (0.74-0.83)
Post Graduate	0.81 (0.77-0.85)	0.84 (0.76-0.92)	0.77 (0.72-0.83)	0.81 (0.76-0.87)
Race				
White & Other White	1.00	1.00	1.00	1.00
Black	1.12 (1.05-1.19)	0.96 (0.85-1.08)*	1.03 (0.94-1.12)*	1.22 (1.13-1.32)
Asian	0.84 (0.80-0.89)	0.84 (0.77-0.92)	0.78 (0.73-0.84)	0.85 (0.80-0.91)
Native American /Alaskan Native	0.93 (0.85-1.01)	0.91 (0.78-1.07)*	0.89 (0.80-1.00)*	0.95 (0.85-1.06)
Hispanic Race	0.90 (0.86-0.94)	0.94 (0.87-1.03)*	0.87 (0.82-0.92)	0.91 (0.86-0.96)
Marital Status: Not Married	1.27 (1.23-1.31)	1.08 (1.02-1.15)	1.26 (1.20-1.31)	1.31 (1.26-1.37)
Place of Birth : Washington State	0.84 (0.82-0.86)	0.81 (0.77-0.85)	0.86 (0.83-0.89)	0.83 (0.80-0.86)
Payor				
Medicaid Recipient	1.29 (1.24-1.33)	1.13 (1.06-1.21)	1.26 (1.21-1.33)	1.33 (1.27-1.40)
Private/Commercial Insurance	0.81 (0.78-0.83)	0.81 (0.76-0.86)	0.81 (0.77-0.85)	0.79 (0.75-0.82)
Prenatal Care: Began 1st Trimester	0.67 (0.65-0.70)	0.77 (0.72-0.81)	0.65 (0.62-0.68)	0.68 (0.65-0.71)
Parity: First Baby	1.38 (1.35-1.42)	1.44 (1.37-1.52)	1.43 (1.38-1.49)	1.33 (1.28-1.37)
Smoked During Pregnancy: Yes	1.30 (1.25-1.34)	1.16 (1.09-1.25)	1.30 (1.25-1.37)	1.32 (1.26-1.38)
Occupation : Other Occupations	1.00	1.00	1.00	1.00
Housewife	1.16 (1.13-1.19)	1.11 (1.05-1.17)	1.13 (1.09-1.17)	1.21 (1.16-1.25)
Student or Under 16	0.77 (0.73-0.82)	0.77 (0.68-0.86)	0.74 (0.68-0.80)	0.77 (0.71-0.83)
Unemployed	1.29 (1.22-1.36)	1.16 (1.04-1.29)	1.26 (1.17-1.36)	1.33 (1.24-1.43)
Maternal Medical Risks				
Diabetes	0.90 (0.85-0.96)	0.88 (0.77-1.00)*	0.91 (0.83-0.99)	0.90 (0.83-0.98)
< 1 year since last FETAL DEATH	0.89 (0.84-0.95)	0.93 (0.82-1.06)*	0.87 (0.78-0.95)	0.91 (0.83-1.00)*
< 1year since last LIVE BIRTH	1.26 (1.14-1.40)	1.11 (0.90-1.38)*	1.26 (1.09-1.46)	1.31 (1.15-1.50)
------ NEIGHBORHOOD CHARACTERISTICS ------				
-- HOUSING --				
% Renter Occupied Housing	1.50 (1.44-1.57)	1.56 (1.46-1.65)	1.51 (1.44-1.58)	1.48 (1.40-1.57)
% Vacant Housing Units	1.20 (1.16-1.25)	1.23 (1.15-1.30)	1.21 (1.16-1.26)	1.21 (1.15-1.26)
-- CROWDING & DENSITY --				
% Urbanized	1.19 (1.15-1.24)	1.17 (1.09-1.25)	1.26 (1.20-1.33)	1.16 (1.10-1.22)
-- STABILITY --				
% Pop in Same House 5 years	0.86 (0.83-0.89)	0.82 (0.77-0.88)	0.85 (0.81-0.89)	0.87 (0.83-0.91)
-- DIVERSITY --				
% With less than HS education	0.87 (0.84-0.91)	0.85 (0.80-0.91)	0.88 (0.84-0.92)	0.89 (0.85-0.94)

* = CI includes 1

a = Comparison groups for Individual Covariates are those with the characteristic (1) versus those without (0) for Individual Characteristics except where REFERENCE is noted/ Comparison Groups for neighborhood characteristics are Top Quintile vs. all others / b = Trimester Movers compared to Non-Movers

MANUSCRIPT 2

A Retrospective Cohort Study of

The Effect of Mobility During Pregnancy and Traffic Exposure

on Adverse Reproductive Outcomes in Washington State, 1992-2004

Part II: *An Assessment of the Association of Adverse Birth Outcomes with Changes in Residence while Pregnant Among Women in Washington State*

May 2009

Sylvia R. Brown, MPH

PhD Candidate

ABSTRACT

The health of a nation is often measured by the health of its newborns; unfortunately, the US fares rather poorly with this measure. Short gestational periods and low birth weight are known to contribute to poor neonatal health and to compromise health later in life, and the rates of these adverse outcomes have increased considerably in the past two decades. This paper examines whether changing residence during pregnancy is associated with three adverse birth outcomes, term low birth weight (LBW), spontaneous preterm (PTD) delivery and small for gestational age (SGA). Approximately 30 percent of pregnant women change residences during pregnancy. Examining the cohort of all Washington state singleton births, 1992-2004, we found that a greater percentage (differences of 4-8%) of mothers of LBW, PTD and SGA babies moved during pregnancy compared to mothers of babies without these outcomes. After adjustments for maternal socio-demographics and pregnancy risk factors, we found that, compared to non-mobile mothers, the odds ratios for LBW and SGA for mobile mothers were elevated overall and across all trimesters (1.0-1.2), and were strongest in the third trimester while for PTD the odds ratio was slightly elevated in the third trimester only (1.0-1.1). We also found that a move anytime during pregnancy modified the effect of primaparity on LBW, SGA and PTD. Compared to multiparous non-movers, the odds ratios for multiparous movers for LBW, SGA and PTD, respectively, were 1.11 (1.04-1.19), 0.99(0.95-1.03) and 1.08(1.05-1.11), the odds ratios for primaparous movers were 2.17(2.04-2.32), 1.25(1.19-1.31) and 1.94(1.89-2.00), and the odds ratios for primaparous non-

movers were 2.28(2.16-2.42), 1.43(1.38-1.48) and 1.99(1.95-2.04). Further research is needed to validate these findings, improve our understanding of the observed associations and etiologies between mobility and LBW, PTD and SGA

INTRODUCTION

The health of a nation is often measured by the health of its newborns; in fact improving the health of newborns is one of the 28 national goals specified in Healthy People 2010(1). The US fares rather very poorly in this regard: the US infant mortality rate is among the highest (27^{th} out of 37^{th} in rank) of all developed countries(2) and the rates of adverse reproductive outcomes, such as low birth weight (LBW) and preterm delivery (PTD), continue to rise. Between 1990 and 2005, the rate of LBW and PTD increased 17% and 20%, respectively, and between 2000 and 2005 alone, these increases were 8% and 9% (3) . In addition to affecting the health of the newborn (1) short gestational periods and low birth weight have also been shown to compromise health later in life (4),(5).

While there are multiple factors known to be associated with LBW, PTD and small for gestational age (SGA), including but not limited to, maternal age, race, education, parity, pregnancy history and general health, the underlying etiology of LBW, PTD and SGA is not fully understood. One aspect that has not been explored in detail is the possible association between a change in residency during pregnancy and these adverse outcomes. Several published studies indicate that between 12% and 32% of women move during pregnancy (6-9). Our recent study of factors associated with maternal mobility during pregnancy (10) has shown similarly that approximately 30% of mothers in Washington State changed residences during their pregnancy and that women who change residency are indeed different than those who do not. While studies in other disciplines have examined the association between mobility and adverse health outcomes (11), these associations are not limited to the prenatal period. In summary, we know that a large percentage of women change residences during pregnancy and that birth outcomes are important to individual and national health; however, we currently have incomplete knowledge on the etiology of LBW, PTD and SGA and an incomplete understanding of the relationship between mobility during pregnancy and LBW, PTD and SGA. These factors motivate this study in which we explore the association between a change in residency during pregnancy and LBW, PTD and SGA and assess whether this association is independent of other factors, such as maternal demographics and socio-economic status (SES). Specifically, our goal is to compare the proportion of movers among the mothers of LBW, PTD, SGA and comparison babies both overall and stratified by trimester, and to assess whether mobility during pregnancy is predictive of, confounds or modifies the effect of known risk factors on these outcomes.

METHODS

Data: In this study, we investigate the cohort of all singleton births born to Washington state residents in Washington State over a thirteen year period (1992-2004), a data set consisting of 978,917, and analyze those with complete reporting for the data fields identified below, a total of 921,162 births..

Outcomes: We examine 3 adverse birth outcomes: term low birth weight (LBW) (> 36 weeks gestation and <2500 grams), spontaneous preterm delivery (PTD) and small for gestational age (SGA). An internal standard was used to determine SGA. This standard was based on the gestation-sex-specific 13-year birth weight distribution for Washington State births for all gestational ages between 20 and 43 weeks. Births falling into the bottom 10% of the observed distribution were labeled SGA. PTD is defined as all births less than 37 weeks gestation and may be classified into subtypes: those which occur after premature membrane rupture, those that are medically indicated i.e., after a primary or repeat c-section, and those not falling into either of theses categories: spontaneous preterm delivery. We consider only spontaneous preterm delivery (PTD) in our study. Some births fell within multiple categories i.e., LBW and SGA or PTD and SGA. Those that did were included separately in the analysis of each outcome. The comparison group in all bivariate and multivariate analyses consisted of births that were not LBW, nor PTD of any subtype nor SGA.

Mobility:

We obtained residential mobility information from the time-at-current-residency data field recorded in months and years on the birth certificate. Beginning in 1989, Washington State mothers have been asked to report “How long at Current Residence” in months and years. This question appears alongside other demographic questions, such as telephone number and mailing address.

For those with mobility data, we determined whether or not a mother moved during pregnancy (mobility status) by ascertaining whether the time-at-current-residence was equal to or greater than the gestational age. This required first an assessment of the validity of recorded gestational age and then a comparison of gestational age to time-at-current-residence. To assess the validity of recorded gestational age, we assumed that birth weight was recorded accurately (12) (13) and then determined whether birth weight, in combination with the calculated gestational age (CGA), which is based on last menstrual cycle, conformed to the ranges suggested by Alexander et al. (14) We utilized physician estimate of gestational age (PGA) when the CGA was missing or was found inconsistent with the recorded birth weight. All births less than 20 weeks gestation were excluded from the analysis since they could not be validated using the Alexander birth weight ranges and births greater than 43 weeks were also excluded as unreliable. Gestational ages found consistent with birth weight were converted to days (weeks * 7). Time-at-current-residence was also converted from years and months to days (total months * 365/12). A mother was classified as a “Mover” when the gestational age, in days, was greater then the time-at-current-residency in days; otherwise, a mother was classified as a “Non-mover”. The specific trimester when a move occurred was determined by comparing the number of days at current residence to the number of days in each trimester (280/3=93.33 days).

Maternal Covariates: In our analysis, we used those maternal covariates that are available on the birth certificate and are known to be predictors of the adverse outcomes under study(15): maternal age (<20, 20-24, 25-29, 30-34,35-39,40 and over), education (less than high school, high school grad or GED, some college, college graduate and post graduate), race (White, Black, Asian, Native American, Hispanic race), ethnicity (Hispanic or not), marital status (married or not), parity (previous birth yes/no), prenatal care history (start of prenatal care in the first trimester, presence of prenatal care data), previous pregnancy history (Yes/no variables: previous PTD, previous c-section, time since last fetal death, time since last live birth, at least 1 prior fetal death), maternal medical risks (Yes/no variables:diabetes, herpes, hypertension, diabetes, having at least 1 risk), smoking history during pregnancy(yes/no) and maternal weight gain (pounds) and Medicaid payor status (yes/no). As noted below, records missing any of these covariates were excluded from the multivariate analysis.

Analysis: We began by examining the distribution of all maternal risk factors by outcome, stratified by whether time-at-current-residence data (mobility data) was missing or not. For all births with mobility data (n=921,162), we ascertained the proportion of mothers who moved during pregnancy for each maternal covariate. For all births with mobility data, we also calculated the unadjusted odds ratio of LBW, PTD and SGA for a move during pregnancy and for a move in each trimester. The comparison group (Comparison-Group) consisted of those births that were neither LBW nor PTD of any subtype nor SGA.

To ascertain the association between mobility during pregnancy and our outcomes of interest, adjusted for known maternal covariates, we modeled the odds of each outcome using unconditional multiple logistic regression. We included only those births with no missing values on any covariates in our modeling efforts (n=583,390). The comparison group in all models (Comparison-Group) consisted of those births that were neither LBW nor PTD of any subtype nor SGA. We included mobility status and all known risk factors in each model, as stated above. In our previous assessment (8), we found that these risk factors (e.g. age, education, race, marital status, Medicaid status) were predictors of mobility during pregnancy. We therefore assessed confounding by examining whether the inclusion of mobility as a risk factor for our outcomes of interest also affected the adjusted odds ratio of each of these maternal risk factors by 10% or more. We examined first order interactions (effect measure modification) between mobility and maternal covariates, and retained in our model only those interaction effects in which the magnitude of the point estimate was at least 10% above/below unity and in which the confidence interval excluded 1. To further describe differences between our two groups (movers vs. non-movers), we also created separate models for each mobility group for each outcome of interest.

We report odds ratios as measures of association between our outcomes of interest and mobility status. These odds ratios may be interpreted as the increased or decreased odds of the occurrence of each outcome given that the mother moved during pregnancy as compared to not having moved during pregnancy. We infer no causal relationship between this measure of mobility and the specified outcome.

Because of the size of our data set, we report 95% confidence levels (CI) as an indication of the precision of our results and do not report p values. All analyses were done using SAS version 9.1(16) and STATA 9 (17).

RESULTS

A total of 978,917 singleton births were born in Washington State to Washington state resident mothers during the thirteen years between 1992 and 2004 (Table 1). 1.6% (n=15,931) of the births were LBW, 5.2% were PTD (n=51,288) and 9.8% (n=95,969) were SGA. Approximately 4.6% (n=44,913) of all births were missing time-at-current-residency data. The proportion of births missing these data was somewhat higher for our outcomes of interest: 5.6% of LBW births, 6.7% of PTD births and 5.5% of SGA births were missing these data. In addition, approximately 1% (n=12,842) of births had missing or out of range gestational age and/or birth weight. We were able to calculate mobility status for 94.1% (n=921,162) of our births. Of these, 1.6% (n=14,899) were LBW, 4.3% (n=39,352) were PTD and 9.8% (n=90,539) were SGA.

Approximately 32% (n=293,582) of all mothers with mobility data *(n=921,162)* moved during pregnancy (Figure 1). These proportions were somewhat higher for mothers of babies with our outcomes of interest: 36.3% of LBW, 32.9% of

PTD and 35.9% of SGA births. The proportion of mothers who changed residency during pregnancy increased with each trimester: 5.5% (n=50,358) of all mothers moved during the first trimester, 12.1% (n=111,019) moved during the second trimester and 14.4% (n=132,205) moved during the third trimester. This pattern was also observed for our outcomes of interest (LBW: 5.3%, 13.1%, 17.9% for 1^{st}, 2^{nd} and 3^{rd} trimesters; similarly for PTD: 3.9%, 12.4%, and16.6%; and SGA: 5.7%, 13.3%, and 16.9%).

Among all mothers with mobility data (n=921,162), the proportion of mothers who changed residence during pregnancy for each maternal characteristic, stratified by outcome, are presented in Table 2. No more than 36% of the mothers of babies with our outcomes of interest changed residences during pregnancy. However, for the entire cohort and across all outcomes, we found proportions of 40% or greater for mothers who were under age 20, with less than a high school education, Black, unmarried, Medicaid recipients, began prenatal care after the first trimester and those who smoked during pregnancy. For example, 43.6% of all Medicaid recipients moved during pregnancy, compared to 25.8% of those did not receive Medicaid. The proportions of LBW, PTD and SGA Medicaid recipients who moved during pregnancy were 46.2%, 42.5% and 46.0%, respectively.

Among all mothers with mobility data (n=921,162), for each of our outcomes of interest, we observed unadjusted odds ratios greater than unity for mothers who moved during pregnancy, compared to mothers who did not move, (Table 3): LBW [OR 1.24(1.20-1.29)], PTD [OR 1.07(1.05-1.09)] and SGA [OR 1.22((1.21-1.24)]. We also observed increasing unadjusted odds ratios for births in which the mother moved later in pregnancy. For example, compared to mothers who did not move during pregnancy, the unadjusted odds ratios for LBW, PTD and SGA among mothers who moved during the first trimester were 1.03(0.96-1.11), 0.71(0.68-0.75) and 1.10(1.07-1.13), respectively, while the unadjusted odds ratios for these outcomes among mothers who moved during the third trimester were, respectively, 1.38(1.32-1.44), 1.22(1.18-1.25) and 1.30(1.27-1.31). The unadjusted odds ratios for LBW, PTD and SGA among mothers who moved during the second trimester were, respectively, 1.19(1.13-1.25), 1.06(1.03-1.10) and 1.20(1.17-1.22).

Approximately 36.7% (n=337,772) of all births with mobility data were excluded from our modeling efforts due to missing covariate data, resulting in a modeling cohort of 583,390 births. 40.2% (n=5,994) of LBW births, 44.0% (n=17,316) of PTD births and 38.9% (n=35,252) of SGA births were excluded for this reason. A smaller proportion [35.9% n=275,277)] of births that were neither term LBW, nor PTD of any subtype nor SGA (comparison group) were excluded. The proportion of movers missing maternal covariate data was similar to that reported for movers and non-movers combined: 36.5% of movers in the entire cohort, 39.8% of LBW movers, 44.2% of PTD movers and 38.6% of SGA movers were excluded due to missing covariate data. The final distribution of our outcomes of interest in the modeling process was as follows: LBW: 1.5%, PTD: 3.78% and SGA: 9.5%. The final distribution of mobility for each outcome of interest in the modeling process was: LBW: 36.6%, PTD: 32.8% and SGA: 36.1%. 31.6% of the comparison group in the modeling process moved during pregnancy.

The adjusted odds ratios associated with a move during pregnancy for each of our outcomes of interest, for those with mobility data but no missing covariate data, are presented in Table 3. We found that the strength of the association with a move during pregnancy varied by parity status. We present the results of all comparisons below as well as results including a term for interaction (effect measure modification). For the latter, we specifically assess whether the combined effect estimate of being primaparous and having moved during pregnancy as compared to being multiparous and not moving during pregnancy differs from the product of the effect estimates for being primaparous as compared to multiparous and moving during pregnancy vs. not moving during pregnancy.

<u>Multiparous movers vs. multiparous non-movers:</u> Adjusted for known maternal risk factors as indicated above, we found that compared to multiparous mothers who did not move during pregnancy, multiparous mothers who did move had an elevated odds ratio for LBW [OR=1.11(1.04-1.19)], a non-elevated odds ratio for PTD [OR= 0.99 (0.95-1.03)] and an elevated odds ratio for SGA [OR=1.08(1.05-1.11)].

Primaparous non-movers vs. multiparous non-movers: Adjusting for other covariates, we found that compared to multiparous non-mobile mothers, primaparous non-mobile mothers had odds ratios elevated above unity for all our outcomes of interest: LBW [OR=2.28 (2.16-2.42)], PTD [OR=1.43 (1.38-1.48)] and SGA [OR=1.99 (1.95-2.04)].

Primaparous movers vs. primaparous non-movers: Adjusting for other covariates, we found that compared to primaparous non-mobile mothers, primaparous mobile mothers had odds ratios below unity for each outcome of interest LBW: 0.95(0.90-1.01), PTD: 0.86(0.82-0.90) and SGA: 0.97(0.95-1.00).

Primaparous movers vs. multiparous movers: Adjusting for other covariates, we found that compared to multiparous movers, primaparous movers had elevated odds ratios for each outcome of interest: LBW: 1.95 (1.81-2.10), PTD: 1.25(1.19-1.31) and SGA: 1.80 (1.75-1.86).

Assessment of Interaction (Table 4): In the absence of an interaction between parity and mobility, we would have expected that the odds ratios for each of our outcomes of interest for primaparous mobile mothers compared to multiparous non-mobile mothers to have been the product of the odds for having moved during pregnancy and the odds for being primaparous i.e. the odd ratios for mobile mothers for our outcomes would have been the following in the absence of an interaction: LBW: 2.54(2.29-2.82), PTD: 1.41 (1.32-1.48) and SGA: 2.15

(2.06-2.24). However, the odds ratios for our interaction term, which represents mobile mothers, were LBW: 0.85 (0.78-0.93), PTD: 0.87 (0.82-0.92) and SGA: 0.90 (0.87-0.94). As a result, the odds ratio for primaparous movers compared to multiparous non-movers for LBW, PTD and SGA were 2.17(2.04-2.32), 1.25(1.19-1.31) and 1.94(1.89-2.00), respectively. These odds ratios are lower than would have been expected in the absence of an interaction. Since the effect of mobility diminishes the effect of primaparity, mobility and primaparity are said to be antagonistic (negative interaction) (18).

In our multivariate analyses for each of our outcomes of interest where we modeled movers and non-movers separately after adjusting for known maternal covariates, we found higher odds ratios for each of our outcomes for non-mobile primaparous mothers (Figure 2). Specifically, the adjusted odds ratios of LBW, PTD and SGA for mobile first time mothers were 1.86 (1.71-2.02), 1.20(1.14-1.27), and 1.77(1.71-1.83), respectively compared to 2.34(2.20-2.48), 1.34(1.29-1.39) and 1.99 (1.94-2.04), respectively for non-mobile first time mothers.

We found that mobility during pregnancy did not affect the association between any of our known risk factors and our outcomes of interest by 10% or more.

DISCUSSION:

In our previous study [(10) ,in review], we compared the socio-demographic patterns of mothers of singleton births between 1999 and 2001 between those who moved during pregnancy and those who did not. We found that mobile mothers were demographically different than non-movers, being older, less well educated, more likely to be African American, unmarried, unemployed, Medicaid recipients and housewives. The movers in this cohort also differed racially and educationally from movers in the general US population.

The current study uses a larger cohort from Washington State to compare birth outcomes in mobile mothers to non-mobile mothers. Results indicate that there is an association between mobility during pregnancy and LBW, PTD and SGA, and that this association is independent of other factors including SES. The motivation for this study emanates from our previous study (10), in which we sought to better understand the predictors of maternal mobility during pregnancy. In that study, we found that many of these predictors – such as age, race and parity – also are known risk factors for LBW, PTD and SGA. In this study, we sought to assess whether, after adjusting for these factors, mobility during pregnancy remains a factor associated with our adverse outcomes of interest.

We found that, proportionally, more mothers of LBW, PTD and SGA births moved during pregnancy compared to mothers of babies that were neither LBW nor PTD of any subtype nor SGA. We also found that, after adjusting for known maternal covariates, babies of multiparous mobile mothers had elevated odds ratios for LBW and SGA compared to multiparous mothers who did not move during pregnancy. This association was strongest for mothers who moved during the third trimester. We also found that the strength of the association between mobility and our outcomes of interest varied by parity status. Compared to primaparous mothers who did not move during pregnancy, primaparous mothers who did move had decreased odds ratios for LBW, PTD and SGA. These associations were strongest for a move during the first trimester.

This is an exploratory analysis and, to our knowledge, the first we know of to directly examine the association between a change in residence during pregnancy and LBW, PTD or SGA. Our results were consistent across all levels of analysis - univariate, bivariate, and adjusted.

There are several plausible explanations for our findings. It is possible that a move during pregnancy is a marker for increased stress during pregnancy. Research not specific to the prenatal period has shown that a change of residence is stressful and can negatively impact health, especially women's health(11). One might also postulate that mobility is a marker for other dimensions of SES that we were not able to capture in our data. For example, income has been shown to be a factor influencing mobility rates. Between 2002 and 2004, 24% of people below the poverty limit compared to only 13% of people above the poverty limit (19) changed residences. In addition, a greater percentage of renters (31%) – i.e. persons with less income than non-renters - moved during this time period than non-renters (7%). However, we did not have access to individual income, household size, poverty status or housing tenure;

therefore, our major SES variable – Medicaid payor status - may not have adequately captured these factors. One might also reason that the protective effect incurred by first time mobile mothers across all trimesters and outcomes is evidence of a heightened awareness of pending maternal responsibilities and a motivation to access better health care and/or kinship support that supersedes any negative affect associated with mobility observed among multiparous mothers. Finally, we might hypothesize that mobility is a proxy for different levels of environmental exposures. Several researchers have investigated possible associations between various environmental exposures and adverse birth outcomes (20-25). In these studies, researchers often use residential address at birth to link each birth to specific environmental exposure values. However, failure to account for mobility, as some of the published studies note, may result in environmental exposure misclassification if the environments around two or more homes differ substantially. Our results are consistent with the effect of an increase in adverse environmental exposures during the third trimester. Given that the third trimester is the time when most fetal growth occurs (26, 27), if a mother moves to an area with higher exposures by the third trimester, then the elevated odds ratio we found for a third trimester move would explain our findings for multiparous mothers. This explanation might also be consistent with our finding of a differential effect of mobility based on parity status since multiparous mothers are more likely to spend more time in the home i.e. at the birth residence while the change of residence for a first time mother may be for reasons that compensate for the increased exposures during periods of susceptibility. This hypothesized explanation suggests that there exists the potential for exposure misclassification if the association between mobility during pregnancy and these adverse outcomes is not accounted for in studies of the association between environmental exposures and birth outcomes. Failure to account for mobility, as some of the published studies note, may result in environmental exposure misclassification if the environments around two or more homes differ substantially. Given the exploratory nature of this study and the absence of additional information noted in the limitations section below, we defer any additional speculation on plausible explanations for our observed results.

The major strength of our study is that, to our knowledge, it is the first epidemiological analysis to directly assess the effect of a change in maternal residence during pregnancy on fetal growth and preterm delivery. A few studies(6-9) have examined the characteristics of maternal mobility during pregnancy; however, their focus was on birth defects rather than LBW, PTD or SGA, they were considerably smaller, and most were case control rather than cohort studies. Moreover, while a recent migration study found that the risks of LBW and SGA were lower for mothers moving within the United States (28), the assessment of mobility in that study was not limited to the prenatal period. These studies suggest to us the importance of considering maternal mobility during pregnancy, and the need for replication of our findings using independent data.

Our study has several additional strengths. We were able to identify mobility status for 95% of our population without incurring additional data collection costs and without relying on information obtained long after delivery. We had a large cohort and therefore were able to assess with precision the association between mobility during pregnancy and adverse birth outcomes. We were also able to examine the association between mobility and our outcomes by trimester and to stratify our cohort by mobility status in order to more clearly describe the differential association of moving with respect to parity.

Our study has several limitations. First, we utilized the time-at-current-residency field on the Washington State birth certificate, in combination with gestational age, to determine mobility status, our outcome of interest. While misreporting of gestational age could bias our results, we attempted to limit this by insuring that the birth weight/fetal age combination was consistent with parameters identified by Alexander et al (14) . Misreporting of time-at-current residence is the second source of bias affecting outcome ascertainment. The time at current residency was added to the Washington State standardized birth certificate in 1989. Mothers record their responses in months and years. We found no publications which utilize these data; nor did we find any independent data to support the accuracy of maternal responses to this question. We therefore do not know whether our understanding and use of the data is consistent with their responses. However, the mobility status of only 2.2% of all births would be affected if gestational age were misreported by 1-2 weeks and therefore bias our results only minimally. We also observed, as noted by Washington State in their documentation which accompanied the birth certificate data (29), digit preference in reporting residency time, with clustered reporting around 6 and 12 months. However, the proportion of births that may have been misclassified based on residency time is expected to be very small and thus would bias our results only minimally. For example, only 2.2% of all births used in the modeling efforts reported an exact residency time of 9 months and 5.4% reported an exact residency time of 6 months.

A second limitation of our study was the use of administrative data collected for other purposes to obtain our independent covariates. We are confident in the internal consistency of the Washington State birth certificate data since these data are routinely examined by Washington State personnel. Also, the data are extensively used both for assessment and surveillance activities by Washington State Government and local health agencies and for research throughout the country. The software utilized by the hospitals to enter birth certificate data has on-line edits to validate various data elements, such as mother's age. In addition, Washington State personnel utilize numerous software programs to check for consistency between data items, such as maternal age and parity, to look for outliers, and to examine 3 year trends for all items. Changes are made wherever possible and queries are made back to the reporting hospital/facility when necessary. Washington State Department of Health personnel examine the birth certificate data both quarterly and yearly (30). We also identified several research studies which assessed the validity and reliability of some of the data elements on the Washington State Birth certificate (29)– specifically birth weight, birth order and maternal smoking (31), maternal diagnoses and procedures (32) (33) (34) maternal pre-existing medical conditions (35), complications of pregnancy and prenatal visits(34). Overall, except for birth weight, these studies suggest an underreporting of these factors. To our knowledge, the validity of many other factors found on the Washington State birth certificate has not been evaluated.

Missing data may also have biased our results. 4.6% (n=44,913) of all mothers were missing time at current residency data and almost 37% (n=337,772) of births with mobility data were excluded from our modeling efforts due to missing covariate data. A higher proportion of births (3-8%) with our outcomes of interest were excluded due to missing data. Since these data appear not to be missing at random, this may have biased our results in either direction. However, the distribution of our outcomes of interest varied only slightly after exclusions for missing data and our multivariate results were consistent with our bivariate results which did not exclude these mothers. Given the large size of our cohort and the small differences in the distributions between those with and without data, it is not likely that any errors incurred would substantially change our results.

Finally, our study is limited by the absence of more detailed information about our mothers, such as why mothers moved during pregnancy, the geographic location from which these mothers moved, how often a mother moved, how long the mother lived at the prior location(s), and specific maternal SES information, such as maternal income, household size and household tenure. It has been shown that overall, people move short distances (36) and the primary reason for these moves is housing related (37), family related or other, including health (19). In the western region of the US, 60% of all females who move remain within the same county of residence and 19% remain within the same state(37). However, we do not know, nor can we assume, that these patterns are the same for the women in our study. It is also possible, as noted above, that the limited individual level SES variables available for analysis may have resulted in uncontrolled confounding that would also modify our reported results. Finally, we cannot determine whether the act of moving itself resulted in the observed associations or whether the population of movers has a different uncaptured risk profile than that of non-movers. Answers to these questions are needed to explain our findings. It is possible that reasons for moving and/or the location and duration at the prior residency would modify our results in either direction.

CONCLUSION:

The goal of this study was to directly explore the relationship between mobility during pregnancy and term LBW, spontaneous PTD and SGA. Our findings are suggestive of the important influence of mobility on our outcomes of interest. They also suggest that mobility may be a potential source for exposure misclassification. However, a better understanding of the characteristics of the mothers who move during pregnancy, why a mother changes residence during pregnancy, the distance between residences and the location of each residence is needed to draw more precise conclusions about the association between mobility during pregnancy on adverse reproductive outcomes.

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Table 1: DISTRIBUTION (%) OF MATERNAL CHARACTERISTICS OF MOTHERS MISSING TIME AT CURRENT RESIDENCY DATA

	ENTIRE COHORT	Comparison-Group [A]	TERM LBW	SPONTANEOUS PTD	SGA
Study Population	978,917	801,951	15,931	51,288	95,969
% Missing Mobility Data	4.59%	4.32%	5.55%	6.69%	5.46%
Age					
< 20	19.08	19.68	18.19	21.93	15.80
20-29	4.71	4.49	5.59	6.45	5.45
30-34	3.48	3.26	4.47	5.32	4.15
35-39	3.54	3.31	4.22	5.13	4.20
40+	4.26	3.96	5.28	6.67	5.13
Education					
< 12 years	15.14	14.94	12.81	17.81	14.72
HS Diploma / GED	4.03	3.92	4.48	4.79	4.47
Some College	3.14	3.06	3.69	3.67	3.58
Baccalaureate Degree	2.20	2.16	2.28	2.79	2.33
Post Graduate	2.10	2.07	2.22	2.33	2.20
Race					
White	7.60	7.85	10.85	5.11	8.38
Black	6.40	5.95	8.15	9.45	6.97
Asian	3.91	3.71	3.66	5.38	4.05
Native American /Alaskan Native	6.55	6.02	6.74	9.75	8.53
Hispanic Race	9.20	9.10	8.58	10.09	9.25
Ethnicity					
Hispanic	8.68	8.56	8.04	**9.77**	8.86
Marital Status					
Not Married	7.36	7.00	7.59	9.98	7.91
Place of Birth					
Washington State	4.39	4.11	5.60	6.52	5.41
Not US Born	6.89	6.77	6.16	8.30	6.86
Payor					
Medicaid	7.07	6.82	7.51	9.06	7.52
Prenatal Care					
Began 1st Trimester	3.79	3.62	4.66	5.20	4.47
Parity					
Primaparous	4.60	4.36	5.40	6.57	5.32
Smoked Cigarettes					
Yes: Smoked During Pregnancy	5.34	4.97	5.89	7.61	5.73
Maternal Medical Risks					
At least 1 Medical Risk	5.13	4.81	5.91	7.59	5.95
Previous C-Section	6.31	5.87	5.97	11.13	6.67
Previous PTD	4.40	3.94	3.85	6.05	4.54
Diabetes	4.31	4.19	3.34	4.59	4.81
Herpes	3.74	3.52	4.51	5.64	4.04
Hypertension	4.42	4.21	4.94	5.85	5.04
Bleeding	4.37	3.86	4.55	7.50	5.62
< 1 year since last live birth	5.57	5.12	3.10	7.70	5.36
< 1 year since last fetal death	3.16	2.97	2.78	4.72	3.65
Missing Paternal Information	8.09	7.54	8.95	11.55	8.86

A = Births that are neither Term LBW, nor PTD of any subtype nor SGA

Table 2: % MOVED DURING PREGNANCY BY OUTCOME: MATERNAL CHARACTERISTICS FOR ALL MOTHERS FOR WHOM MOBILITY STATUS COULD BE DETERMINED

	ENTIRE COHORT		COMPARISON-GROUP [A]		TERM LBW		SPONTANEOUS PTD		SGA	
	Total N	**% Moved**	**Total N**	**% Moved**	**Total N**	**% Moved**	**Total N**	**% Moved**	**Total N**	**% Moved**
Study Population	921,162	31.87	766,733	31.43%	14,899	36.32	39,352	32.86	90,539	35.94
AGE: < 20	92,913	49.95	71,960	50.24	2,261	51.44	5,793	45.68	13,069	50.98
20-29	483,594	37.50	403,123	37.19	7,595	40.95	20,580	37.81	48,179	40.52
30-34	219,832	20.54	187,458	20.22	3,001	24.33	7,994	20.58	18,252	23.29
35-39	102,773	16.84	86,210	16.57	1,619	20.32	4,049	17.46	8,940	19.30
40+	21,678	14.88	17,683	14.58	413	18.93	921	16.18	2,053	17.88
EDUCATION: < 12 years	150,842	43.06	118,151	42.81	3,426	46.41	8,683	41.98	19,922	45.75
HS Diploma / GED	263,015	35.94	217,076	35.68	4,591	37.73	11,615	36.69	27,274	38.66
Some College	228,185	29.59	193,568	29.38	3,201	33.46	8,686	29.18	19,627	32.60
Baccalaureate	129,943	21.14	112,854	21.15	1,491	22.40	4,199	18.77	9,710	22.99
Post Graduate	79,888	20.11	69,153	20.03	869	21.17	2,577	18.78	6,132	22.21
RACE: White	671,747	30.76	569.671	30.35	9,781	35.50	25,793	31.45	58,930	35.15
Black	35,865	42.22	26,218	41.84	1,105	47.78	2,223	41.48	6,076	45.26
Asian	69,037	28.42	53,426	28.27	1,570	29.62	3,627	28.51	10,203	29.86
Native American /Alaskan Native	20,170	37.23	16,351	37.28	356	39.04	1,400	35.71	1,700	38.41
Hispanic Race	98,030	37.89	79,055	37.56	1,639	40.57	5,309	39.24	11,010	41.21
MARITAL STATUS: Not Married	248,409	44.74	194,332	44.83	5,766	46.69	13,916	42.38	32,889	46.25
Married	671,086	27.07	57,114	26.83	9,095	29.74	25,349	27.61	57,423	30.00
PAYOR*:* Medicaid	297,610	43.63	237,754	43.49	6,171	46.15	15,233	42.48	36,283	45.96
Not Medicaid	568,337	25.82	483,619	25.59	7,692	29.02	21,569	26.12	48,311	28.79
PARITY: Primaparous	375,413	37.12	303,003	37.11	7,519	38.77	16,706	35.74	45,541	38.89
1+ Previous Births	524,679	28.18	446,377	27.63	6,999	33.95	21,691	30.66	42,730	32.90
PRENATAL CARE: Began Tri 1	699,519	29.17	589,004	28.80	10,474	32.96	27,465	29.76	64,849	32.92
Began > Tri 1	141,803	44.61	114,220	44,37	2,862	48.36	7,281	43.29	16,775	47.73
Paternal Data **Missing**	225,308	39.68	177,646	39.31	4,909	44.16	12,483	39.25	28,326	42.95
Not Missing	695,854	29.34	589,087	29.95	9,990	32.47	26,869	29.89	62,213	32.75
SMOKED DURING PREGNANCY: Yes	129,260	43.26	96,581	43.31	4,208	43.37	6,933	42.41	21,886	43.96
No	764,789	29.98	647,850	29.70	10,256	33.39	31,075	30.69	65,886	33.29

Table 2: % MOVED DURING PREGNANCY BY OUTCOME: MATERNAL CHARACTERISTICS FOR ALL MOTHERS FOR WHOM MOBILITY STATUS COULD BE DETERMINED (continued)

	ENTIRE COHORT		COMPARISON-GROUP [A]		TERM LBW		SPONTANEOUS PTD		SGA	
	Total N	**% Moved**	**Total N**	**% Moved**	**Total N**	**% Moved**	**Total N**	**% Moved**	**Total N**	**% Moved**
Maternal Medical Risks										
At least 1	443,528	31.90	357,939	31.44	9,190	36.72	20,049	33.37	48,280	35.81
No	477,634	31.84	408,794	31.41	5,709	35.68	19,303	32.33	42,259	36.09
Previous C-section: Yes	22,949	29.57	16,574	28.69	,992 >>	33.77	489	32.52	3,914	33.65
No	898,213	31.93	750,159	31,49	13,907	36.51	38,863	32.86	86,625	36.04
Previous PTD: Yes	12,752	29.98	7,692	28.71	623	32.42	1,587	32.58	2,310	34.63
No	908,410	31.90	759,041	31,45	14,276	36.49	37,765	32.87	88,229	35.97
Diabetes: Yes	31,204	26.67	24,992	26.55	545	26.97	1,342	27.42	2,783	27.13
No	889,958	32.05	741,741	31,59	14,354	36.68	38,010	33.05	87,756	36.22
Herpes: Yes	24,321	31.88	20,346	31.45	357	39.78	783	31.03	2,323	36.76
No	896,841	31.87	746,387	31,43	14,542	36.24	38,569	32.90	88,216	35.92
Hypertension: Yes	50,119	30.75	36,177	30.63	2,031	32.30	1,538	31.73	8,292	32.26
No	871,043	31.94	730,556	31,47	12,868	36.96	37,814	32.91	82,247	36.31
Bleeding: Yes	14,185	29.62	10,494	29.48	313	36.42	890	30.22	1,574	32.91
No	906,977	31.91	756,239	31,49	14,586	36.32	38,462	32.92	88,965	35.99
<1year since last fetal death: Yes	21,595	28.25	17,673	27.64	385	33.77	1,069	29.09	2,084	34.31
No	899,567	31.96	749,060	31,52	14,514	36.39	38,283	32.97	88,455	35.98
<1 year since last live birth: Yes	10,627	39.24	8,013	38.45	216	46.30	1,045	42.30	1,125	44.62
No	910,535	31.78	758,720	31,35	14,683	36.18	38,307	32.60	89,414	35.83

A= Births that are neither Term LBW, nor PTD of any subtype nor SGA

TABLE 3: UNADJUSTED[A] AND ADJUSTED[B] MOBILITY ODDS RATIOS FOR TERM LBW, SPONTANEOUS PTD AND SGA

		COMPARISON GROUP [C]	TERM LBW	SPONTANEOUS PTD	SGA
Population	With Mobility data	766,733	14,899	39,352	90,539
	With no Missing Covariate Data	491,456	8,905	22,036	55,287
	% of Births with No Missing Covariate data among those with mobility data	64.10%	59.8%	56.0%	61.1%
Moved During Pregnancy [D]	Unadjusted: All Mothers		1.24(1.20-1.29)*	1.07(1.05-1.09)*	1.22(1.21-1.24)*
	Adjusted: Multiparous Movers vs. Multiparous non-Movers		1.11(1.04-1.19)*	0.99(0.95-1.03)	1.08(1.05-1.11)*
	Adjusted: Primaparous Movers vs. Primaparous non-movers		0.95(0.90-1.01)	0.86(0.82-0.90)*	0.97(0.95-1.00)
Moved First Trimester [D]	Unadjusted: All Mothers		1.03(0.96-1.11)	0.71(0.68-0.75)*	1.10(1.07-1.13)*
	Adjusted: Multiparous Movers vs. Multiparous non-Movers		1.07(0.93-1.23)	0.76(0.70-0.83)*	1.01(0.95-1.07)
	Adjusted: Primaparous Movers vs. Primaparous non-movers		0.74(0.65-0.86)*	0.58 (0.52-0.64)*	0.92(0.87-0.97)*
Moved Second Trimester [D]	Unadjusted: All Mothers		1.19(1.13-1.25)*	1.06(1.03-1.10)*	1.20(1.17-1.22)*
	Adjusted: Multiparous Movers vs. Multiparous non-Movers		1.08 (0.98-1.19)	0.99*0.93-1.05)	1.07(1.03-1.11)*
	Adjusted Primaparous Movers vs. Primaparous non-movers		0.95(0.88-1.04)	0.88(0.83-0.94)*	0.96(0.93-1.00)
Moved Third Trimester [D]	Unadjusted		1.38(1.32-1.44)*	1.22(1.18-1.25)*	1.30(1.27-1.32)*
	Adjusted: Multiparous Movers vs. Multiparous non-Movers		1.17(1.07-1.27)*	1.07(1.02-1.13)*	1.11(1.07-1.15)*
	Adjusted: Primaparous Movers vs. Primaparous non-movers		1.02(0.95-1.10)	0.95(0.90-1.00)	1.00(0.97-1.04)

*Confidence Interval excludes 1
A = Includes all mothers with mobility data (n=921,126)
B= ADJUSTED ODDS RATIOS: Multivariate analyses adjusted for known maternal covariates: maternal age, education, race, ethnicity, marital status, parity, prenatal care history, previous pregnancy history, maternal medical risks, smoking history during pregnancy, maternal weight gain and Medicaid status: Includes only births with no missing covariate data
C= All births that were neither Term LBW, nor PTD of any subtype nor SGA
D=All movers and Trimester specific movers compared to Comparison-Group non-movers

Table 4: ASSESSMENT OF INTERACTION
Comparison of Adjusted Odds Ratios by Parity and Mobility Status In the Presence vs. Absence of Multiplicative Interaction

--------------------- TERM LBW ------------------

	MOVERS	NON-MOVERS	PRODUCT*
PRIMAPAROUS	2.17 (2.04-2.32)#	2.28 (2.16-2.42)	2.54 (2.29-2.82)
MULTIPAROUS	1.11 (1.04-1.19)	1.00	

---------- SPONTANEOUS PTD ------------------------

	MOVERS	NON-MOVERS	PRODUCT*
PRIMAPAROUS	1.25 (1.19-1.31)#	1.43 (1.38-1.48)	1.41 (1.32-1.48)
MULTIPAROUS	0.99 (0.95-1.03)	1.00	

--------------------- SGA -------------------------

	MOVERS	NON-MOVERS	PRODUCT*
PRIMAPAROUS	1.94 (1.89-2.00) #	1.99 (1.95-2.04)	2.15 (2.06-2.24)
MULTIPAROUS	1..08 (1.05-1.11)	1.00	

* Product of main effects (moving * primaparous) : expected odds ratio in the absence of an interaction
# Odds ratio for primaparous movers compared to multiparous non-movers: odds ratios in the presence of the interaction

FIGURE 1: MOBILITY PROPORTIONS BY TRIMESTER AND OUTCOME

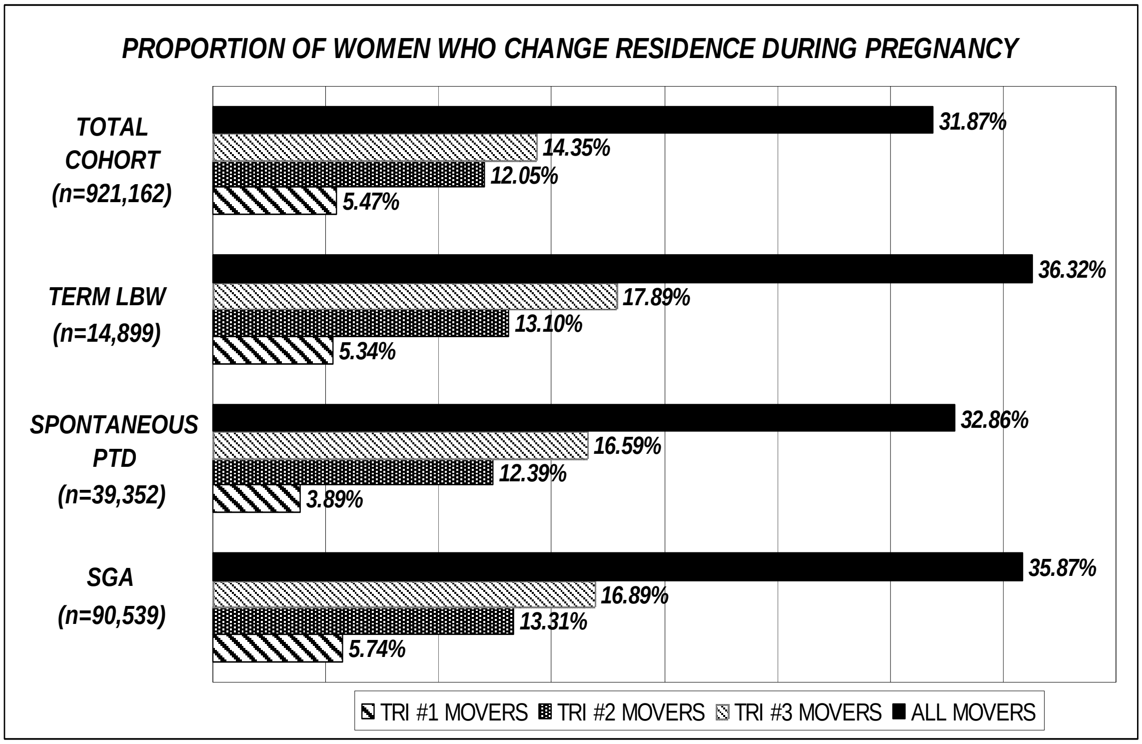
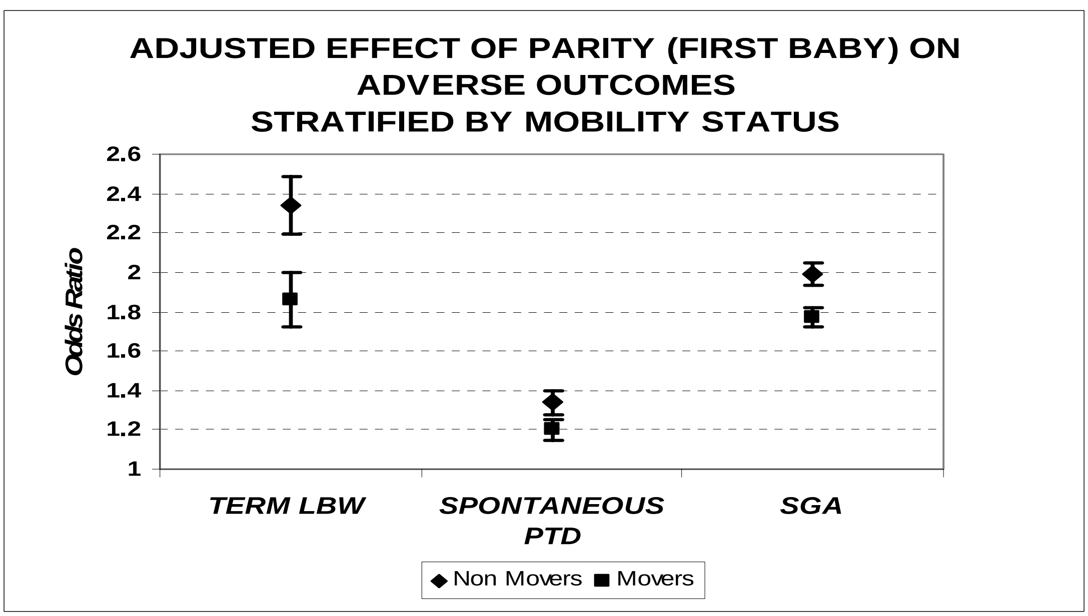


FIGURE 2: ADVERSE OUTCOMES FOR PRIMAPAROUS MOTHERS STRATIFIED BY MOBILITY STATUS



MANUSCRIPT 3

A Retrospective Cohort Study of

The Effect of Mobility During Pregnancy and Traffic Exposure

on Adverse Reproductive Outcomes in Washington State, 1992-2004

Part III: *An Assessment of the Association between Traffic Exposure and Adverse Birth Outcomes and the effect of mobility during pregnancy on the association in the Puget Sound Region of Washington State*

May 2009

Sylvia R. Brown, MPH

PhD Candidate

ABSTRACT

This historical cohort study examines whether the distance of a mother's residence to highly trafficked roadways, adjusted for the annual average daily traffic volume (AADT), as an estimate of exposure to ambient air pollution, is associated with adverse birth outcomes [term low birth weight (LBW), spontaneous preterm birth (PTD) or small for gestational age (SGA)]. In addition, we assess whether these associations differ for mothers who changed residency during pregnancy as compared with those who were residentially stable. The purpose of this assessment is to ascertain whether there may be misclassification of environmental exposures for mothers who change residence because the exposures were estimated at the birth residence only rather than at all of the mother's residences during pregnancy.

The study base of 126,390 births is comprised of all singleton births, born between 1994 and 2004 in the Puget Sound Region of Washington State, for which we were able to obtain complete covariate data, including location of maternal residence at the time of birth (birth residence), but restricted to those for which the birth residence was located within 3280 ft. (1000m) of a major roadway. Distances between the birth residence and major roadways were derived using Arcinfo. For each birth, exposure was estimated using annual average daily traffic (AADT) data obtained from the Washington State Department of Transportation, and linked to the major roadways for each birth residence using SAS.

We found that, compared to the birth residences that did not have LBW, PTD or SGA births, the birth residences with LBW, PTD and SGA births were located closer to roadways and had higher weighted traffic exposures. We also found that the birth residences of movers, compared to those of non-movers, were closer to the nearest roadway and had higher weighted traffic exposures. The adjusted odds ratios for residing within 750 ft. of a roadway compared to beyond 750 ft, were marginally elevated for LBW [1.05(0.95-1.16)] and SGA [1.04(1.00-1.09)] but were not elevated for PTD [0.98(0.92-1.05)]. Similar patterns were found for residences within 1640 ft. and 3280 ft. of a roadway. When we stratified these data by mobility status, we observed higher adjusted odds ratios for living within 750 ft. of a roadway, as compared with living more than 750 ft. from a roadway, for movers than for non-movers [LBW 1.12(0.96-1.32) vs. 1.00(0.88-1.14); PTD 1.03 (0.92-1.15) vs. 0.96 (0.88-1.04); SGA 1.05 (0.98-1.13) vs. 1.03 (0.98-1.09)]. When we weighted the distance by traffic density (AADT), generally we found adjusted odds ratios greater than 1.0 for each of our outcomes of interest for each quintile of exposure, compared to the first (lowest exposure) quintile. We also found that non-movers had higher adjusted odds ratios than movers when data were limited to those within 750 ft. of a major roadway and 1640 ft. of a major roadway, but not for those within 3280 ft. of a major roadway.

To our knowledge this was the first study to utilize time-at-current-residency data recorded on the Washington State birth certificate. As such, it makes a valuable contribution by providing a preliminary look at the potential importance of maternal change in residence in the investigation of associations between environmental exposures and adverse birth outcomes.

INTRODUCTION

Identifying ways to decrease the high rates of low birth weight (LBW) and preterm birth (PTD) in the US is a major public health challenge at both the state and national levels. These rates continue to rise (1), affecting both the health of the newborn (2) and the health of the child later in life (3, 4). While there are multiple factors known to be associated with LBW, PTD and small for gestational age (SGA), such as maternal age and race, the underlying etiology of these outcomes is not well understood.

In studying this issue, researchers have hypothesized that maternal exposure to air pollution during pregnancy may be causally associated with adverse reproductive outcomes. Over the past decade, multiple studies have been conducted to examine this possible association for LBW (term and preterm)(5-22), SGA (10, 15, 21, 23, 24), and PTD (6, 10, 14, 15, 20, 21, 25, 26). Several studies assigned proximate ambient pollutant concentration measurements to birth residences, often reporting statistically significant associations between carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and particulate matter (PM) and different measures of fetal growth and gestational duration for varying time periods during pregnancy (27).

However, some researchers have suggested that these regional air monitoring data do not adequately capture intra-community spatial variation, leading to erroneous results (21, 28, 29). To address this, some have used measures of traffic volume - the primary source of criteria air pollutants in many urban areas – as their measure of exposure to ambient air pollution. For example, Yang et al. (30), examined in Taiwan the association between distance to a heavily trafficked roadway and PTD among primaparous mothers. The adjusted odds ratio for PTD was 1.30 (1.03-1.65) for those living within 500m of the freeway versus those living between 500m and 1500m, after adjusting for maternal age and education, marital status and infant gender. Genereux et al. (31) examined, in the city of Montreal, Canada, the association between distance to highways and LBW, PTD and SGA. The adjusted odds ratios were 1.17 (1.04-1.33), 1.14 (1.02-1.27) and 1.06 (0.96-1.17), respectively, for living within 200m of a highway vs. beyond, after adjusting for maternal age, marital status, country of birth, history of prior stillbirth, birth order (first vs. subsequent) and year of birth. Brauer et al. (21), examined the association between traffic related air pollution and SGA and term LBW among births in the Vancouver, British Columbia, metropolitan area using three exposure metrics: 1) distance to highways, 2) ambient monitor concentrations, and 3) Land Use Regression (LUR) which utilized proximity to traffic, land use, population density and topographic data. They found elevated adjusted odds ratios for SGA [1.26(1.07-1.49)] and term LBW [1.22(0.81-1.97)] for living within 50m (164 feet) of major highways, as well as less elevated odds ratios for SGA with exposures based on LUR and ambient monitor data. Wilhelm and Ritz (32), in a case control study of births in Southern California, 1994-1996, used both ambient air quality and traffic density in the same analyses. They used Distance Weighted Traffic Density (DWTD), a metric based on Annual

Average Daily Traffic (AADT) counts and distance to roadway, to examine the association between air pollution and LBW and PTD. They adjusted their data for birth year, infant sex, maternal race, maternal age, maternal education, number of births, parity, prenatal care, season of conception, and average annual background concentrations of CO, O_3, PM_{10} and NO_2, measured at the nearest ambient air monitoring station. They found elevated risks for women whose third trimester fell during the fall/winter months. For maternal residences within 750 feet of the roadway, they also found elevated odds ratios for the quintiles of DWTD exposure, compared to the lowest exposure quintile, for PTD and LBW births.

One limitation of these studies is that there may be exposure misclassification if the assignment of exposures is based on the birth residence, if the mother changed residence(s) during pregnancy, and if the exposures differ among the homes. Previous research reported that between 12% and 35% of women move during pregnancy.(21, 33-36) Two recent poster presentations at academic research conferences examined mobility patterns within two separate case-controls studies of birth defects, one based in Atlanta (37) and the other in New York State (38). Each found that more than 20% of women moved during pregnancy and that there was no difference in mobility patterns between cases and controls. Researchers from the New York State study found a high measure of agreement between exposures based on residential history and those based on the birth residences but suggest that this may not be the case when using smaller geographic areas for assigning exposures. Researchers from the Atlanta based study reported differences in socio-economic characteristics between those who moved and those who did not. Our investigation found similarly that approximately 32% of Washington State mothers move during pregnancy and that almost half of these (45%) moved in the third trimester (39).

Some studies have assumed that exposure misclassification attributable to change in residence during pregnancy would likely be non-differential, biasing the results toward the null. Two studies have addressed this issue directly. (7, 23) Ritz et al. investigated the possible association between PTD and air pollution, specifically PM10 and CO, among a cohort of births in Southern California 1989-1993 (26). In a follow-up analysis of the same cases and controls (40) these authors limited subjects to those who did not move during pregnancy (based on the 40% of the subjects who provided residence histories). They reported larger but less precise effect measures for non-movers than the entire study population, consistent with random exposure misclassification of movers due to change in residence, although participation bias cannot be ruled out as an explanation. Brauer et al avoided this issue by constructing residential histories for all births in their cohort, utilizing British Columbia health plan registry files, hospital discharge record and physician billing records and then assigning exposures to the different maternal residences during pregnancy. (21).

This historical cohort study examines the possible association between maternal traffic exposure and LBW, PTD and SGA in the Puget Sound Region of Washington State. We chose this study area because of the high levels of air pollution[1] and the availability of information on maternal "time at current residence" on the Washington State Birth Certificate since 1989. Our specific aims are:

1) to examine whether distance to highly trafficked roadways and/or exposures to air pollutants estimated from annual average traffic statistics, in the Puget Sound Area between 1994 and 2004, are associated with increased risk of term low birth weight (LBW), spontaneous preterm birth (PTD) or small for gestational age (SGA);

2) to assess whether the observed associations vary by whether or not a mother changed residence location during pregnancy.

METHODS

BIRTH DATA (Figure 1a)

SOURCE: The Washington State Department of Health (WSDOH) provided birth certificate data for the years 1994 through 2004, including latitude, longitude and 2000 block group of the birth residence, and time-at-current-residence (in months

[1] The Puget Sound Region has had high levels of air pollution and was designated a non-attainment area for carbon monoxide, ozone, and PM_{10} upon enactment of the Clean Air Act Amendments in 1990, Air Contaminant Emissions Inventories for the Puget Sound area indicate an ever increasing contribution of on-road sources to CO emissions and a consistent 30% contribution of on-road sources to VOCs – a precursor of ozone (41. Agency PSCA. Air Quality Data Summary , July 2005 found at http://www.pscleanair.org/airq/reports.shtml, 2004.. As stated in a 2004 report of the Puget Sound Air Agency, " on-road vehicles continue to be the most significant contributors to both criteria pollutant and air toxics emissions in the Puget Sound airshed…."The Agency has suggested that between 85 to 95% of all CO emissions may come from motor vehicle exhaust (42. Puget Sound Clean Air Agency, Air Quality Data Summary , January 2004 found at http://www.pscleanair.org/airq/reports.shtml..

and years) (43). We included in our study births from the four counties which comprise the Puget Sound Region (King, Kitsap, Pierce and Snohomish), the most populated region in the state. (44). To be able to investigate the role of a mother's change in residence during pregnancy, we further restricted our study base to records reporting data for time-at-current-residence, birth weight and gestational age. Birth weight and gestational age are both required to ascertain mobility status, as detailed below. To maximize our sensitivity to detect possible exposure effects from proximity to traffic (i.e., air pollutants) we limit our analyses to those residences with 1000 meters (3280 feet) of a roadway. Of the 25 studies published between 1999 and 2006 that reported a positive association between traffic exposure and adverse health outcomes in infants, children and adults, all but one utilized buffers of 500m or less (45). We therefore felt that restricting our study base to those within 1000m only, given our large study base, was sufficient to assess the associations we were exploring. Finally, we evaluated only those births with complete data on maternal covariates known to be risk factors for our three outcomes of interest. To assess the possible bias incurred by this last restriction, we compared the distribution of mobility status, outcomes and maternal risk factors between those births with complete covariate data versus those without complete covariate data.

We accomplished the restriction to 1000m using ARCINFO (46), the 2003 Washington State Linear Referencing System (LRS), and the latitude and longitude for each birth residence. "A LRS is a method for locating data (point features such as intersections, linear features such as guardrails, and events such as collisions) at a measured distance along a particular linear feature from its beginning. A spatial LRS is a representation of linear elements by X,Y coordinates in relationship to the earth's surface." (47)

BIRTH OUTCOMES, MOBILITY STATUS, MATERNAL COVARIATES*:*

Outcomes: We examine 3 adverse birth outcomes: term low birth weight (LBW) (> 36 weeks gestation and <2500 grams), spontaneous preterm delivery (PTD) (< 37 weeks gestation) and small for gestational age (SGA). An internal standard was used to determine SGA. This standard was based on the gestation-sex-specific 13-year birth weight distribution for all Washington State births 1992 - 2004 (chosen to provide consistency between our previous study of the relationship between mobility and SGA(48) for all gestational ages between 20 and 43 weeks. Births falling into the bottom 10% of the observed distribution were labeled SGA. PTD may be classified into subtypes: those which occur after premature membrane rupture, those that are medically indicated i.e. after a primary or repeat c-section, and those not falling into either of theses categories: spontaneous preterm delivery. The biological mechanisms by which air pollution may cause adverse reproductive outcomes is currently unknown (27); however, multiple hypothesized mechanisms have been suggested. (17) For example, it has been hypothesized that a reduction in oxygen delivery to the uterus due to acute or chronic exposure to CO may affect fetal growth or that inflammation of the airways may negatively impact umbilical and placental blood flow, thus affecting fetal growth and PTD (49). The biological mechanisms for two subtypes of PTD are known. PTD following ruptured membranes is likely due to intrauterine infection and medically indicated PTD is likely the result of adverse maternal medical conditions, such as eclampsia, fetal compromise, or both (50). We therefore limited our analysis to spontaneous PTD subgroup whose etiology is not yet understood.

Births falling into multiple categories, i.e., LBW and SGA or PTD and SGA, were included in the analysis of each outcome. The comparison group in all bivariate and multivariate analyses consisted of births that were neither LBW, nor PTD of any subtype, nor SGA.

Mobility: We obtained residential mobility information from the time-at-current-residency data field recorded in months and years on the birth certificate. Beginning in 1989, Washington State mothers have been asked to report “How long at Current Residence” in months and years. This question appears alongside other demographic questions, such as telephone number and mailing address.

For those with mobility data, we determined whether or not a mother moved during pregnancy (mobility status) by ascertaining whether the time-at-current-residence was equal to or greater than the gestational age. This required first an assessment of the validity of recorded gestational age and then a comparison of gestational age to time-at-current-residence. To assess the validity of recorded gestational age, we assumed that birth weight was recorded accurately (51) (52) and then determined whether birth weight, in combination with the calculated gestational age (CGA), which is based on last menstrual cycle, conformed to the ranges suggested by Alexander et al. (53) We utilized physician estimate of gestational age (PGA) when the CGA was missing or was found inconsistent with the recorded birth weight. All births less than 20 weeks gestation were excluded from the analysis since they could not be validated using the Alexander birth weight ranges and births greater than 43 weeks were also excluded as unreliable. Gestational ages found consistent with birth weight were converted to days (weeks * 7). Time-at-current-residence was also converted from years and months to days (total months * 365/12). A mother was classified as a "mover" when the gestational age, in days, was greater then the time-at-current-residency in days; otherwise, a mother was classified as a "non-mover". The specific trimester when a move occurred was determined by comparing the number of days at current residence to the number of days in each trimester (280/3=93.33 days).

Maternal Covariates: In our analysis, we used those maternal covariates that are available on the birth certificate and are known to be predictors of the adverse outcomes under study (54): maternal age (<20, 20-24, 25-29, 30-34,35-39,40 and over), education (less than high school, high school grad or GED, some college, college graduate and post graduate), race (White, Black, Asian, Native American, Hispanic race), ethnicity (Hispanic or not), marital status (married or not), parity (no previous birth), prenatal care history (start of prenatal care in the first trimester, presence of prenatal care data), previous pregnancy history (previous PTD, previous c-section, time since last fetal death, time since last live birth, at least 1 prior fetal death), maternal medical risks (diabetes, herpes, hypertension, diabetes, having at least 1 risk), smoking history during pregnancy(yes/no), maternal weight gain and infant sex. We examined the Spearman correlations among all these variables and found all, save one, to be less than 0.55 and most being <0.20. One dimension of race - Hispanic race – and ethnicity (Hispanic vs. not) were highly correlated. However, since they measured different constructs (race vs. ethnicity), both were retained in our analyses. We believe that the likelihood of overadjustment in our modeling efforts was minimal.

TRAFFIC EXPOSURE DATA (Figure 1b)

The Washington State Department of Transportation (WSDOT) provided Annual Average Daily Traffic (AADT) counts from the Highway Performance Monitoring System (HPMS) for all line segments along the state roadways in the counties of interest for the years 1994 through 2004. HPMS is a national traffic data collection system run by the United States Department of Transportation. AADT counts are derived from raw traffic counts which include continuous counts, control or seasonal counts and coverage or short duration counts. Seasonal (M_h), day of week (D_h), axle (A_i,), growth factors (G_h), time of day, and equipment adjustments are applied to raw traffic data (VOl_{hi})to derive AADT (55-57). AADT counts are designed to be unbiased estimates of average annual counts. In general, a 24-hour axle count, is converted to AADT ($AADT_{hi}$) - the annual average daily travel at location i of factor group h, with factors groups consisting of at least 6 homogeneous road segments – according to the following formula, with additional corrections made for time of day and equipment, as indicated (55):

$$AADT_{hi} = VOL_{hi} * M_h * D_h * A_i * G_h \quad (3\text{-}1)$$

AADT line segments are sections with homogeneous volumes " i.e., the traffic volume does not change throughout the segment.(58). A change of +/-10% in traffic volume is needed to create a new line segment.

WSDOT personnel converted yearly HPMS AADT data to the Accumulated Route Mileage (ARM) configuration of the LRS utilizing their in-house software product, ARMCALC. We received ESRI formatted shapefiles, with their corresponding data tables, in DBF format, for each year between 1994 and 2004. Each file included a unique identifier for each AADT line segment and the AADT count for each line segment. The counts we received are total counts and are not specific to vehicle-type (car vs. truck) or fuel-type (gasoline vs. diesel).

We choose to limit our maximum buffer distance to 1,000 meters based on our review of previous studies. We found that buffer sizes used in studies of traffic and other adverse non-reproductive health outcomes in children, such as cancer

(59-62) and respiratory health (63, 64) have varied widely, from 50 ft. (58) to 1500 feet or more (55,61). We also found that most studies on traffic and adverse health outcomes for different age groups used buffers no greater than 500m (45). Once we implemented the 1000m restriction, we then examined our exposure metrics in multiple buffers of increasing radius from the birth residence. We found no definitive results in this effort from which to guide our selection of buffers to be reported herein. We therefore chose to report our results for the buffers utilized in the previous studies published prior to 2008 of traffic and adverse reproductive outcomes in order to facilitate comparison with prior research in this field. These were the 1640 ft buffer (500m) used by Yang et al (30) and the 750 ft. buffer used by Wilhelm and Ritz (32). We therefore report on effects in the following buffers: <=750 ft. >750 ft-1640 ft. (500m) and >1640 ft-3280 ft. (1000m).

Using ARCINFO, we identified all birth residences located within 3280 ft. of at least one line segment on the LRS, all road segments within the 3280 ft. radius of each birth residence and the distance, in feet, between each birth residence and each of these line segments. We imported these results, along with the DBF AADT data tables, into SAS and, for each road segment for each birth, we extracted the AADT count and calculated the weighted AADT by dividing the AADT count by the distance to that road segment. Using this information, we constructed several metrics for each birth. For consistency, we report all distances and buffer radii in feet.

We classified each birth into a set of three nested buffers of distance to the nearest line segment. If the nearest distance between a birth residence and at least one line segment was <=750 ft, then that birth was assigned to the 750 ft. buffer. If the nearest distance was <=1640 ft, then the birth was assigned to the 1640 ft. buffer as well as the 750 ft. butter. By definition, all births in our study base were assigned to the 3280 ft. buffer. We used different distance buffers and weighted our traffic count by inverse distance because typically the concentration of air pollutants decreases as distance to the source increases.

For each birth, we calculated the total weighted traffic exposure in each buffer (750 ft., 1640 ft, 3280 ft) by summing the weighted AADT values for each line segment located within that buffer. We then classified the weighted AADT values within each buffer into quintiles. Births located in more than one buffer were assigned to the exposure quintile in each buffer according to its weighted traffic exposure within that specific buffer. This metric is important since it provides a more precise measure of exposure – traffic volume plus distance – than that provided by distance alone and provides insight into whether there exists a greater health risk with greater exposures for those living within each buffer area. Note: that mothers in the closest buffer will also be members of the large sized buffers.

ANALYSIS (Figure 1c)

We defined the following groups for our analyses: all births combined, comparison-group births, births with our outcomes of interest and, also, all of these groups stratified by mobility status. For each of these groups, we calculated the mean, standard deviation, and median distance to the nearest line segment, the unweighted AADT count and weighted AADT count of the nearest line segment. We calculated the percentage of births living within each exposure buffer for each of these groups, the distribution of births in each successive buffer and the unadjusted associations (crude odds ratios) for living within vs. beyond these buffers. Using unconditional multiple logistic regression, we calculated the adjusted association between birth residences within vs. beyond each buffer. We adjusted for known maternal covariates to take account of the important background information i.e. risk factors documented in the literature (65). We calculated the median total weighted traffic exposure within each cumulative buffer and also the unadjusted and adjusted (for known maternal covariates) association between each quintile of weighted AADT exposure versus the first quintile within each buffer. The outcome comparison group in all analyses consisted of births that were neither LBW nor PTD of any subtype nor SGA.

QUALITY ASSURANCE EFFORTS:

Since our exposure metrics were dependent on the accuracy of the geocoding of birth residences and the positional accuracy of the LRS, we undertook two separate processes to assess the effect of possible errors associated with these data. We recognize that there is additional uncertainty in the geocoding process that this QA effort is unable to address.

1. <u>Geocoding of Birth Residences</u>: The Washington State Department of Health, Division of Information Resource Management (DIRM) is responsible for geocoding the address at birth as it appears on the Washington State birth certificate. DIRM has developed a comprehensive iterative process to complete this task (66). Briefly, for our four counties of interest, addresses as they appear on the birth record are standardized based on street number/name and zip code then matched to street centerlines files with address ranges or parcel centroids provided by the local county government. A matching "score" is generated by the geocoding process to reflect the accuracy of the match. We utilized this score as a measure to assess the magnitude of bias associated with errors in the geocoding process. Specifically, we examined the distribution of the maximum geocoding score across all outcomes and buffers and assessed the extent to which our multivariate results would change if we restricted our analyses to those with the maximum geocoding score (score=100).

<u>2. Positional Accuracy of Linear Referencing System (LRS) and traffic exposure assessment:</u> The positional accuracy of the geocoded birth residences can vary by +/- 25 ft. (67) and the positional error of the LRS can vary by up to a maximum of +/- 80 ft. (68). Thus, our distance measures, on which our exposure metrics are based, could vary by +/- 105 feet. To assess the magnitude of the potential bias associated with this source of error, we performed a series of sensitivity analyses. We recalculated all exposure metrics for the 750 ft. buffer and 3280 ft.

buffer after adjusting all distances by +105 ft. and -105 ft. We then reanalyzed the data using the revised metrics and examined the results to determine the extent, at the extremes, to which these variations might affect our results. For purposes of brevity, we present the results of the +105 feet analysis only.

Because of the size of our data set, we report 95% confidence levels (CI) as an indication of the precision of our results and do not report p values. The objective of this study was to explore the association between traffic and adverse births outcomes, modified by mobility status. In our results, unity usually fell in the lower tail of the observed confidence limits. However, we believe in the importance of and present all effect measures, whether or not the CI includes unity. Associations may exist even when statistically significant results are not found. (65, 69) All values within a 95% confidence interval are not equally likely. The most likely effect is the point estimate itself and the likelihood decreases as one moves away toward the limits (65, 69).

All analyses were done using SAS version 9.1(70).

<u>RESULTS: ALL BIRTH COMBINED</u>

STUDY BASE: The development of the study base is depicted in Figure 1a. A total of 828,326 singleton births were born in Washington State to mothers resident in Washington State during the eleven years between 1994 and 2004, inclusive. More than half of these (n=458,640) were to mothers residing in the

Puget Sound area at the time of birth. 1.6% of the births in the 4 county-area were LBW, 5.3% were PTD and 9.7% were SGA.

Of the 458,640 births, 3.7% (n=17,042) were missing time-at-current-residency data. A higher proportion of births with our outcomes of interest were missing these data: 4.7% of the LBW births, 5.7% of the PTD births and 4.6% of the SGA births. Mobility status was therefore determined for 435,186 birth mothers (Table 1) after excluding births with missing birth weight, missing or out of range estimates of gestational age, and/or inconsistent birth weight/gestational age combinations

Approximately 54.5% of the 435,186 births (n=237,228) lived within 3280 ft. of a road segment. 53.3% (n=126,390) of these had complete covariate data and comprise our study base. A higher percentage of the comparison-group births had complete covariate data (54%) compared to LBW (49.9%), PTD (45.6%) and SGA (51.3%) births.

A summary of the births with and without covariate data is provided in Table 2.

DISTANCE ONLY ANALYSIS:

Results of our distance only analyses are provided in Tables 3a-3b and Figures 2a-2c. The median distance to the nearest line segment was 1,380 ft. for the comparison-group. The births residences of LBW, PTD and SGA births were located 130 feet, 40 feet and 60 feet closer to the nearest line segment than the comparison-group, with median distances of 1,250 ft, 1340 ft, and 1320 ft, respectively. The median unweighted and weighted AADT counts of the nearest line segment were higher for births with our outcomes of interest compared to the comparison-group. The median traffic count of the nearest line segment for the comparison-group (32,899) was 768 less than that for LBW births (33,667), 1,966 less than that for PTD births (1966) and 1,070 less than that for SGA births (33,969). The median weighted AADT count of the nearest line segment was 30.96 for the comparison-group compared to 35.60 for LBW births, 34.90 for PTD births and, 35.72 for SGA births.

The distribution of birth outcomes in each exposure buffer by outcome and mobility status are provided in Table 4, Figures 3a-3d, 4a-4b. Of the 126,390 births in our study base, 26.4% (n=33,400) lived within 750 ft. of the nearest line segment, representing approximately 26.2 % of the comparison-group, 28.5% of LBW births, 26.7% of PTD births and 28.3% of SGA births. 56.6% (n=74,049) of our study population (an additional 30.2%, n=40,649) lived within 1640.2 ft. Approximately 58.3% of the comparison-group, 62.6% of LBW births, 59.9% of PTD births and 60.2% of SGA births lived within this buffer.

When we compared births resident within the 750 ft. buffer to the rest of our study base (those from 750 ft- 1000m), we observed crude odds ratios elevated above unity for each of our outcomes of interest (Table 5a). The adjusted odds ratios were elevated above unity for LBW [(OR=1.05(0.95-1.16)] and SGA [OR=1.04(1.00-1.09)] and marginally below unity for PTD [OR=0.98(0.92-1.05)]. When we compared births within the 1640 ft. buffer to those beyond this buffer, we found both crude and adjusted odds ratios elevated above unity for each of our outcomes of interest. The adjusted odds ratio was statistically significant at the .05 level for LBW [1.12(1.02-1.23)] and marginally elevated above unity for PTD [1.02(0.96-1.08)] and SGA [1.02(0.98-1.06)].

WEIGHTED TRAFFIC EXPOSURE ANALYSIS:

We found that for all buffers and outcomes, the median total weighted traffic exposure was greater for LBW, PTD and SGA births compared to the comparison-group *(Table 6, Figure 5a-5c)*. For example, for those living within the 750 ft. buffer, the median total weighted traffic exposure for the comparison-group was 120.89 compared to 129.85 for LBW births, 134.26 for PTD births and 131.01 for SGA births.

LBW: (Table 7a-Figures 6a-6c) We found crude odds ratios for LBW elevated above unity for each quintile of exposure, compared to the first, in each buffer, with one exception. The adjusted odds ratios for LBW for the quintiles of exposure in each buffer, compared to the first quintile, were smaller, but most were elevated above unity although none were statistically significant at the .05 level. For example, the adjusted odds ratios for the quintiles of exposure for births in the 750 ft. buffer, compared to the first quintile were: 2nd quintile:

1.02(0.77-1.34), 3rd quintile: 1.09(0.83-1.43), 4th quintile: 1.09(0.83-1.44) and 5th quintile: 0.94 (0.71-1.25). We observed the suggestion of a dose-response relationship in both the crude and adjusted odds ratios in the 3280 ft. buffer only. For example the adjusted odds ratios for LBW for each quintile of exposure, compared to the first, in the 3280 ft. buffer were: 2nd quintile: 0.90(0.78-1.06), 3rd quintile: 1.04(0.90-1.21), 4th quintile: 1.12(0.97-1.30) and 5th quintile: 1.12 (0.96-1.29). All of the 95% confidence intervals for the adjusted odds ratios for LBW included unity.

PTD: *(Table 7a-Figures 6a-6c)* We found crude odds ratios for PTD elevated above unity for each quintile of exposure, compared to the first, in each buffer. The adjusted odds ratios for PTD for the quintiles of exposure in each buffer, compared to the first quintile, with one exception, were all elevated above unity. For example, the adjusted odds ratios in the 750 ft. buffer were 2nd quintile: 1.01(0.83-1.21), 3rd quintile: 1.00(0.83-1.20), 4th quintile: 1.05(0.87-1.26) and 5th quintile: 1.07 (0.89-1.29). Only exposure in 5th quintile in the 1640 ft. buffer showed a statistically significant elevated association with PTD [1.15(1.01-1.30)]; the remaining 95% confidence intervals for the adjusted odds ratios included unity.

SGA: *(Table 7a-Figures 6a-6c)* We found crude odds ratios for SGA elevated above unity for each quintile of exposure, compared to the first, in each buffer. The adjusted odds ratios for SGA for the quintiles of exposure in each buffer, compared to the first quintile, with one exception, were all elevated above unity. For example, the adjusted odds ratios in the 750 ft. buffer, compared to the 1st quintile, were 2nd quintile 1.03(0.91-1.16), 3rd quintile 1.11(0.98-1.24), 4th quintile 1.06(0.94-1.19) and 5th quintile 1.08(0.96-1.22). A suggestion of a dose response effect is observed in the crude odds ratios within the 1640 ft. and 3280 ft. buffers. The 95% confidence intervals for most of the adjusted odds ratios for SGA included unity with three exceptions in the 3280 ft. buffer. The elevated odds ratios for SGA were statistically significant in the 3280 ft. buffer for : 3rd [quintile [1.15(1.08-1.22)] 4th quintile [1.09(1.02-1.16)] and 5th quintile of exposure [1.13(1.06-1.20)] as compared to the first quintile.

RESULTS: STRATIFIED BY MOBILITY STATUS

STUDY BASE:

Approximately 30.5% (n=132,643) of the 435,186 births with ascertainable mobility status moved during pregnancy (Table 1). 59.1% of these movers (n=78,355) compared to 52.5% of non-movers (n=158.873) lived within 3280 ft. of the nearest line segment.

The percentage of mothers who were mobile that were included our study base was approximately the same (32.6% vs. 33.4%) as the percentage of mothers who were mobile who were excluded due to missing covariate data (Table 2). The percentage of included vs. excluded movers resident within the 750 ft. buffer was only marginally different (28.1% vs. 26.4%). Thus, while our study base consisted of proportionally fewer women with risk factors for our outcomes of interest, we observed no difference in the proportion of mobile vs. non-mobile mothers included vs. excluded from the analysis and therefore would not expect our mobility results to be biased based on implementing this particular exclusion criteria.

(Tables 3a-3b) Approximately 33.4% of all births (n=42,209) and 33.0% of comparison-group births (n=35,059) moved during pregnancy. A higher percentage of mobile mothers was found among LBW (36.6% n=715), PTD (34.5%, n=1,608) and SGA (37.3%, n=4,562) births.

DISTANCE ONLY ANALYSIS

(Tables 3a-3b, Figures 2a-2c) On average, movers lived 160 feet closer to the nearest line segment than non-movers. The median distance to the nearest line segment was 1,270 feet for all movers versus 1,430 ft. for all non-movers. Comparison-group movers lived 170 feet closer to the nearest line segment than comparison-group non-movers (1,270 ft. vs.1,440 ft.). LBW, PTD and SGA movers lived 200 ft, 140 ft. and 180 ft. closer to a roadway than LBW, PTD and SGA non-movers, respectively. The median distance to the nearest line segment for LBW, PTD and SGA movers was 1,150 ft., 1,250 ft. and 1,210 ft., respectively compared to the median distance for LBW, PTD and SGA non-movers: 1,360 ft, 1,390 ft. and 1,390 ft., respectively.

The median unweighted traffic count of the nearest line segment was higher for all movers (34,288) compared to all non-movers (32,432) and for comparison-group movers (34,112) versus comparison-group non-movers (32,128). The median unweighted AADT count for LBW, PTD and SGA movers was 35,067, 36,815 and 35,078, respectively. These counts are higher than those for LBW (32,878), PTD (33,995.50) and SGA (33,529) non-movers. These patterns are similar for weighted traffic counts.

(Table 4, Figure 3e-3l, 4a-4b) A greater percentage of movers compared to non-movers lived within the 750 ft. and 1640 ft. buffers. For example, approximately 29.2% of comparison-group movers vs. 24.7% of comparison-group non-movers lived within the 750 ft. buffer, a difference of 4.5%. Approximately 33.0% of LBW movers vs. 25.9% of LBW non-movers (7.1% difference), 30.4% of PTD movers vs. 24.7% of PTD non-movers (5.7% difference) and 31.5% of SGA movers vs. 26.5% of SGA non-movers (5% difference) lived in this buffer. A greater percentage of non-movers were therefore resident 1640 ft to 3280 ft. from the nearest line segment.

(Tables 5b-5d) When we compared births resident within the 750 ft. buffer to those beyond this buffer i.e. >750 ft. to 3280 ft. from the nearest line segment, we observed crude odds ratios elevated at or above unity for each mobility stratum for each of our outcomes of interest. Overall, the crude odds ratios for residence within vs. beyond the 750 ft. buffer were higher for movers than for non-movers for all outcomes. The crude odds ratios for LBW for mothers resident in the 1640

ft. buffer vs. beyond were greater for movers than non-movers. The adjusted odds ratio for LBW for residence within the 750 ft. buffer vs. beyond was 1.12(0.96-1.32) for movers vs. 1.00(0.88-1.14) for non-movers. The adjusted odds ratio for residence within the 1640 ft. buffer was statistically significant [1.18(1.01-1.39)] for movers and elevated but not statistically significant [1.09(0.97-1.23)] for non-movers. The adjusted odds ratio for PTD for residence within the 750 ft. buffer vs. beyond was marginally elevated above unity for movers [1.03(0.92-1.15)] and marginally below unity for non-movers [0.96(0.88-1.04)]. This was reversed for residence within the 1640 ft. buffer vs. beyond where the adjusted odds ratio for PTD for movers was 0.98(0.89-1.09) and 1.04(0.97-1.12) for non-movers. The adjusted odds ratio for SGA for residence within the 750 ft. buffer vs. beyond was marginally elevated above unity for movers [1.05 (0.98-1.13)] and non-movers [1.03 (0.98-1.09)]. For residence within 1640 ft. vs. beyond, the adjusted odds ratios for SGA were 1.01(0.94-1.08) for movers and 1.02(.98-1.08) for non-movers. Most of the above confidence intervals included unity.

WEIGHTED TRAFFIC EXPOSURE ANALYSIS:

(Table 6, Figure 5a-5c): We found that for all buffers and outcomes, the median total weighted traffic exposure was greater for movers compared to non-movers. For example, for those living within the 750 ft. buffer, the median total weighted traffic exposure for the comparison-group movers was 133 compared to 114 for comparison-group non-movers. For mothers resident within the 750 ft. buffer,

the median weighted traffic exposure for LBW movers was 131 compared to 129 for LBW non-movers, 151 for PTD movers vs. 125 for PTD non-movers and 144 for SGA movers vs. 122 for SGA non-movers.

LBW: (Table 7b, Figures 7a-7c):

We found crude and adjusted odds ratios for LBW elevated above unity for each quintile of exposure, compared to the 1st quintile, for non-movers within the 750 ft. buffer but below unity for movers in the same buffer. For example, the adjusted odds ratios for LBW, for the quintiles of exposure, compared to the first quintile, in the 750 ft. buffer for non-movers were: 2nd quintile: 1.27(0.88-1.82), 3rd quintile: 1.27(0.88-1.83), 4th quintile: 1.24(0.86-1.79) and 5th quintile: 1.14 (0.78-1.67). For movers, these adjusted odds ratios were 2nd quintile: 0.75(0.48-1.16), 3rd quintile: 0.89(0.59-1.36), 4th quintile: 0.91(0.60-1.37) and 5th quintile: 0.72 (0.47-1.10). Conversely, for those resident within 3280 buffer, i.e., the entire cohort, the adjusted odds ratios are higher among movers than non-movers. The odds ratios for LBW among non-movers in this buffer were : 2nd quintile: 0.84(0.70-1.01), 3rd quintile: 0.99(0.83-1.18), 4th quintile: 1.06(0.89-1.27) and 5th quintile: 1.07 (0.89-1.28). For movers, these adjusted odds ratios were 2nd quintile: 1.06(0.81-1.40), 3rd quintile: 1.19(0.91-1.56), 4th quintile: 1.28(0.99-1.66) and 5th quintile: 1.24 (0.96-1.61). The 95% CIs of all adjusted odds ratios for the quintiles of exposure for LBW for all buffers included unity.

PTD: (Table 7c, Figures 8a-8c): We found crude and adjusted odds ratios for PTD elevated above unity for each quintile of exposure, compared to the first, for non-movers within the 750 ft. buffer. By comparison, these odds ratios were smaller for movers within this buffer. For example, the adjusted odds ratios for PTD in the 750 ft. buffer for non-movers were: 2nd quintile: 1.07(0.85-1.36), 3rd quintile: 1.06(0.84-1.34), 4th quintile: 1.04(0.82-1.32) and 5th quintile: 1.09 (0.86-1.38). For movers, these adjusted odds ratios were 2nd quintile: 0.89(0.65-1.21), 3rd quintile: 0.88(0.64-1.19), 4th quintile: 1.03(0.77-1.39) and 5th quintile: 1.02 (0.76-1.36). We observe no consistent pattern when comparing the odds ratios for the quintiles of exposure within the 3280 buffer. The adjusted odds ratios for PTD for the quintiles of exposure for non-movers in the 3280 ft. buffer, compared to the first quintile, were: 2nd quintile: 1.07(0.95-1.20), 3rd quintile: 1.00(0.89-1.13), 4th quintile: 1.07(0.95-1.20) and 5th quintile: 1.08 (0.96-1.22). For movers, these adjusted odds ratios were 2nd quintile: 1.02(0.86-1.22), 3rd quintile: 1.02(0.86-1.22), 4th quintile: 1.07(0.90-1.27) and 5th quintile: 1.08 (0.92-1.28). The 95% CIs of all adjusted odds ratios for the quintiles of exposure for PTD for all buffers included unity.

SGA: (Table 7c, Figures 9a-9c): We found most crude and adjusted odds ratios for SGA elevated above unity for each quintile of exposure, compared to the first quintile, for both movers and non-movers resident within the 750 ft. buffer. The crude and adjusted odds ratios were greater for non-movers compared to movers in the 750 ft. buffer. For example, the adjusted odds ratios for SGA for the quintiles of exposure, compared to the first, for non-movers in the 750 ft. buffer were : 2nd quintile: 1.08(0.93-1.25), 3rd quintile: 1.16(1.00-1.35), 4th quintile: 1.08(0.92-1.25) and 5th quintile: 1.10 (0.94-1.28) while that for movers was: 2nd quintile: 0.96(0.79-1.16), 3rd quintile: 1.03(0.85-1.24), 4th quintile: 1.02(0.84-1.23) and 5th quintile: 1.05 (0.87-1.26). Conversely, the adjusted odds ratios for SGA for the quintiles of exposure, compared to the first, for movers were larger than those for non-movers in the 3280 ft. buffer. The adjusted odds ratios for SGA for non-movers in this buffer were elevated above unity for some quintiles of exposure and statistically significant for several: the 2nd quintile: 1.01(0.94-1.09), 3rd quintile: 1.13(1.05-1.22), 4th quintile: 1.08(1.00-1.17), 5th quintile: 1.11 (1.02-1.20) compared to 2nd quintile: 1.10(0.98-1.23), 3rd quintile: 1.18(1.06-1.32), 4th quintile: 1.11(0.99-1.24) and 5th quintile: 1.18 (1.06-1.31) for movers.

QUALITY ASSURANCE

1. Geocoding of Birth Addresses: We found that a high percentage (94%) of the birth addresses matched exactly (score=100) to local parcel data and that the proportion of perfect geocoding scores was consistent across all buffers, outcomes and mobility strata. For example, of those living within 750 ft. of the nearest line segment, 93.7% had perfect geocoding scores and of those living within 1640 ft, 93.8% had perfect geocoding scores. Approximately 93.3% of LBW births, 93.6% of PTD births, 93.8% of SGA births and 94.0% of comparison-group births had perfect geocoding scores. 92.8% of movers and 94.6% of non-movers also had perfect scores.

The magnitude of our adjusted associations varied only slightly when we restricted our multivariate analyses to births with perfect geocoding scores. The percentage change in the odds ratios varied from less than 1% to no more than 10%. Most changes were between 1 and 2%. For example, the adjusted odds ratios for LBW for all births combined for the quintiles of exposure in the 3280 ft. buffer, compared to the first quintile were (Table 7a) as follows: 2^{nd} quintile: 0.91(0.78-1.06), 3^{rd} quintile: 1.05(0.90-1.21), 4^{th} quintile: 1.12(0.97-1.30), and 5^{th} quintile: 1.11(0.96-1.29). The adjusted odds ratios for births with perfect scores were : 2^{nd} quintile: 0.91(0.78-1.07), 3^{rd} quintile: 1.05(0.90-1.21), 0.98(0.84-1.15), 4^{th} quintile: 1.11(0.95-1.28) and 5^{th} quintile: 1.10(0.95-1.28).

2. <u>Positional Accuracy of Linear Referencing System (LRS) and traffic exposure assessment</u> The results of our sensitivity analyses indicate that with an adjustment of +105 ft, 2.3% of the entire cohort (n=2,959 births) would no longer live within the 3280 ft. buffer. None of these births had exposures within the highest(5^{th}) exposure quintile and less than 1% (n=26 0.10%) had exposures in the fourth quintile. Of the 33,400 in the 750 ft. buffer, approximately 16% (n=5,331) would no longer be categorized as residing in that buffer. Approximately 17% (n=907) of these had exposures in the uppermost 2 quintiles.

After adjusting all distances by +105 feet, we found the same distance patterns identified above: Birth with our outcomes of interest lived closer to the nearest line segment than Comparison-group births and movers lived closer than non-movers. For example, the revised median distance to the nearest line segment for all births combined was 1,480 ft., compared to LBW: 1,350 ft., PTD: 1,450 ft. and SGA: 1,430 ft.). The revised median nearest distance to the nearest line segment for all movers was 1370 ft. compared to 1,530 for non-movers.

A change in the quintile distribution of weighted traffic exposure would result if we were to add 105 ft. to all the distances. The magnitude of these changes varies by buffer. For example, with the addition of 105 feet to all distances, the revised cut point for the top quintile of the 750 ft. buffer would be 406.24 compared to 362.36 used in the reported analysis; for the 3280 ft. buffer, the cut point would be 200.08 compared to 198.86.

With an adjustment of +105 ft., most of the adjusted odds ratios for the quintiles of exposures, compared to the first, for LBW, PTD and SGA for those living within the 750 ft. buffer, differed from that reported in Table 7a by 10% or less. Overall, the reanalysis resulted in lower adjusted odds ratios. All adjusted odds ratios resulting from the sensitivity analysis were included in the 95% confidence intervals of those adjusted odds ratios reported in Table 7a.

DISCUSSION

Several studies have examined the possible association between exposure to ambient pollution and adverse birth outcomes. The results have not been entirely consistent but, on average, suggest a small positive effect with substantial variability. (27, 71-73) Only four studies used measures of traffic intensity – such as distance to heavily trafficked roadways and/or distance weighted by traffic volume - as a proxy for air pollution levels in studies of adverse birth outcomes. (21) (32) (30) (31). These studies report weakly positive associations (Tables 8,9a-9b).

In this study, we had two goals: (1) to assess the possible association of traffic exposure with adverse birth outcomes; and (2) to assess whether that association was modified in some way by the mothers' residential histories.

To address the first issue, we used a traditional approach, estimating exposure by geographic distance to major roadway, by traffic volume (AADT) and by weighting the traffic volume by geographic distance. Our results for distance to major roadway generally showed that adverse outcomes were more common closer to major roadways, after adjustment for covariates, consistent with the other studies that used a similar methodology (Table 8). Our analyses with distance weighted AADT also showed higher weighted traffic counts for births with our outcomes of interest and slightly elevated odds ratios, in general, with confidence intervals that usually included unity, consistent with Wilhelm and Ritz (32), the only other study that modeled the data in this manner (Tables 9a, 9b).

To address the second issue, we investigated one possible source of variation and bias - misclassification of exposure due to maternal change of residence.

Previous studies have shown that between 12% and 35% of women move during pregnancy, with the number increasing as the time to birth decreases, and more movement over shorter rather than longer distances. This issue has been addressed previously by two studies, as noted above. (21) (26), Brauer and colleagues, in the only other cohort study directly addressing this type of exposure misclassification, avoided the problem by developing monthly exposure estimates from longitudinal residential histories constructed by compiling residence location information, "from the time of pregnancy until birth from postal codes and associated dates recorded in provincial health plan registry files, and from all hospital discharge and physician billing records for each mother."(21) No analysis in that study assessed the impact of using birth address only. Ritz and colleagues addressed this issue using data from a nested case control study (26) by analyzing the possible association between specific air pollutants and adverse birth outcomes, both for the entire data set and separately for only those who in which pregnant women did not change residence location during pregnancy.(26) They found that when the data were restricted to mothers who did not move, the effect measures increased slightly, possibly due to reduced exposure misclassification, and confidence intervals widened, due to decreased sample size from exclusion of mothers who moved during pregnancy. Consistent with Ritz's results, our study using quintiles of weighted traffic exposures showed stronger associations, in general, for non-movers as compared both to movers alone and to all births combined within the first two buffers, possibly due to decreased exposure misclassification. However, we see a reversal of this effect in the most distant buffer, possibly reflecting decreased influence from distant roadways and possibly other confounding exposures (Tables 7a-7d, Table 10 and Figures 7a-7c, 8a-8c, 9a-9c).

In short, our data support previous studies that showed positive associations of proximity to traffic, proximate traffic volume and proximate traffic volume weighted by distance, with adverse birth outcomes, although there is substantial uncertainty. Exposure misclassification attributable to change in residence (and environmental exposures) during pregnancy weakened the observed effect and increased the observed variability. These observations of elevated risks were more consistent at the closer distances, suggesting that other factors may alter the effects at greater distances.

Our sensitivity analyses suggest that restricting our study base to those with perfect geocoding scores would have minimal effect on our results for the 750 ft. buffer although errors in the positional accuracy of the LRS and birth residences could attenuate the magnitude of the adjusted odds ratios.

Our study has numerous strengths. First, we drew our study population for a large cohort using routinely collected administrative data, obviating the need for direct, active data collection. This emphasizes both the utility of such data sets maintained by health departments nationwide and removes many of the biases that may arise in studies using specially-collected data. As a consequence of using several years of a statewide database, our study also was far larger than the only other study to assess directly the effect of change of residence. Second, our study applied specific traffic exposure measures to the individual birth, rather than using aggregate air monitoring data. This approach shows the utility of routinely collected traffic data; the individual exposure estimates increase the specificity of our data analyses. Third, we have demonstrated how the use of a data field contained on birth certificates in only four states nationwide (Connecticut, Maine, Missouri and Washington State) - that of length of mother's residence at the birth residence - can facilitate investigation of the role of change in residence on the investigation of environmental hazards. We are fortunate to have been given the opportunity to take advantage of the foresight, nearly 20 years ago, by the Washington State Department of Health, in adding this data element.

There are several limitations to our exposure metrics which are not unique to this study. For example, some, but not all studies (74) have differentiated between car and truck traffic. We were unable to do so with the data we were given. We recognize that emissions vary by vehicle speed, age and condition but neither we, nor other similar studies, had information on these factors. Other important factors influencing traffic exposure, such as variations in topography, wind conditions, housing characteristics, regional differences such as the presence of polluting industries, indoor pollution, and neighborhood SES characteristics, were also not specifically accounted for in our study, However, while these limitations may have reduced the sensitivity of our study, we do not believe that these limitations resulted in invalid associations.

To our knowledge, we are the first study to use time-at-current-residency data recorded on the Washington State birth certificate. While this makes our study unique, it does introduce limitations which can be addressed through further research on these data. . We utilized the time-at-current-residency field on the Washington State birth certificate, in combination with gestational age, to determine mobility status. While misreporting of gestational age could bias our results, we attempted to limit this by insuring that the birth weight/fetal age combination was consistent with parameters identified by Alexander et al (53). The mobility status of only 3.3% of all births would be affected if gestational age were misreported by 1-2 weeks. Misreporting of time-at-current residence, would also affect the determination of mobility status. Mothers record their responses in months and years. We found no independent data to support the accuracy of maternal responses to this question. We also observed, digit preference in reporting residency time, with clustered reporting around 6 and 12 months, as noted by the Washington State Department of Health, in the documentation that accompanied the birth certificate data (75)'. The proportion of births that may have been misclassified, however, is expected to be very small and thus bias our results only minimally.

Our study, as others, is also limited by the use of administrative data collected for other purposes. We are confident in the internal consistency of the Washington State birth certificate data, which have been screened with software utilized by the hospitals to enter birth certificate data, providing on-line edits to validate various data elements, such as mother's age. Washington State personnel also utilize numerous software programs to check for consistency between data items, such as maternal age and parity, to look for outliers, and to examine 3 year trends for all items. Changes are made wherever possible and queries are made back to the reporting hospital/facility when necessary. Washington State personnel examine the birth certificate data both quarterly and yearly (76). We also identified several research studies which assessed the validity and reliability of some of the data elements on the Washington State Birth certificate (75)– specifically birth weight, birth order and maternal smoking (77), maternal diagnoses and procedures (78) (79) (80) maternal pre-existing medical conditions (81), complications of pregnancy and prenatal visits(80). Overall, except for birth weight, these studies suggest an underreporting of these factors. However, to our knowledge, the validity of many other factors found on the Washington States birth certificate has not been evaluated in detail A systematic underreporting of residence time or the maternal covariates could bias our results in either direction.

Missing data can also create biases. In this study, only 3.7% of mothers in the four county Puget Sound Region were missing time at current residency data and a slightly higher proportion of births with our outcomes of interest were missing these data: 4.7% of LBW births, 5.7% of PTD births and 4.6% of SGA births. Of greater concern is the very large amount of missing covariate data. In this paper, we restricted our study to those births with no missing covariate data in order to have a common study base for the many analyses we performed. As a result, our study base consisted of proportionally fewer women at risk for our outcomes of interest; however, we observed no differences in the proportion of mobile mothers among those excluded or included. While the difference in risk factors would affect the results of our univariate and bivariate analyses, our multivariate analyses should not be affected since we controlled for those risk factors. However, it is possible that mothers with complete covariate data differed from those excluded in ways not captured in our data. This uncontrolled confounding would likely be differential and affect our results in either direction.

Ours was an exploratory study which has suggested numerous approaches for future research. While not within the scope of this paper, we recommend the following alternative approaches to further explore the association between traffic exposure and adverse reproductive outcomes. The first is an analysis focused on the years 1994 through 1996. These are the years for which we have traffic data in which the Puget Sound Region was a non-attainment area for carbon monoxide, ozone, and PM_{10}, i.e. the years with greatest exposures. Also suggested are analyses restricted to season of birth or season of conception(27) and/or births in urban areas only when/where the highest concentrations of CO in the Puget Sounds region occur. An analysis focused on the I5 corridor, rather than all roadways, would focus on the regional roadway with the greatest traffic volume. Additional analyses limited to the years immediately surrounding the 2000 Census are suggested in order to accurately capture neighborhood SES and thus adjust for neighborhood level confounding factors. We also suggest analyses reflecting time-activity patterns, such as incorporating occupational exposures and/or focusing on women with potentially the greatest exposures, such as multiparous non-mobile women who are most likely to spend more time at the birth residence. Since our exposure metric did not account for the length of each road segment or the proportion of the line segment to which the mother was exposed we suggest using another traffic exposure metric, such as Vehicle Miles Travelled (VMT), which factors in these metrics. Another alternative approach would be the use of Land Use Regression Model (LUR), such as that used by Brauer et al (21), which incorporates multiple factors, including traffic exposure, ambient air concentrations, topography and weather conditions to estimate exposures. Other analytic approaches might include an examination of the independent risks of residency within each buffer rather than the effect of cumulative buffers and analyses to look at the spatial variation of exposure and outcomes. Finally , it is possible that the use of AADT - a yearly average which, by definition, adjusts for seasonal and temporal variation – minimizes temporal variation and thus provides a measure of chronic and not acute exposures. However, acute exposures are considered by some to be more relevant when assessing association between air pollution and adverse outcomes (28). Daily or monthly exposure metrics, if available, may be more appropriate.

It is unclear whether the different effects we observed for movers vs. non-movers are due to differences in traffic exposure and/or other differences not captured in our analysis i.e. whether there is exposure misclassification based on birth residence and/or residual confounding. For example, we did find that movers have higher traffic exposures based on the birth residence. If traffic exposure affects outcome, we would have expected to find the adjusted odds ratios for the quintiles of exposure for the 750 ft. buffer to be higher for movers compared to non-movers. Since those odds ratios were in fact lower, one might hypothesize that the calculated exposure misrepresented their true exposure, that either chronic long term exposure for the non-movers or an acute exposure during the time when the movers were not present increased the risk for non-movers. Alternatively, one might also hypothesize that the differences between movers and non-movers is a proxy for other factors, such as SES or health and that we were unable to fully capture these factors in our analyses. Also, perhaps there are different classes of movers based on the reasons for moving and/or the location of the former residence and that our dichotomization of mobility status oversimplifies and/or dilutes these differences. Finally, if the observed differences between movers and non-movers were due to exposure misclassification only, we might have expected to observe differences between movers and non-movers across all outcomes within each buffer. However, the observed differences in the adjusted odds ratios between movers and non-movers, for example, within the 750 ft. and 3280 ft. buffers were large for LBW but marginally different for PTD and SGA births. Our results suggest differences based on mobility but the nature, magnitude and direction of those differences remain unknown at this time, Clearly, the differential effect of residential mobility on adverse reproductive outcomes needs to be explored in more depth.

In his recent review of traffic and health, Samet (82) pointed out that there are multiple factors associated with traffic exposure in addition to air pollution: housing, noise exposure, occupation, residential location, and SES. While we have attempted to control for many of these factors, such as SES and mobility status, we were unable to do so for all within the scope of this paper. Therefore, uncontrolled confounding likely exists. “Additionally, difficult methodological issues call for caution in interpreting the epidemiological findings; there is potential for uncontrolled confounding, exposure measures are subject to misclassification, and uncertainty is not fully accounted for.”(82) Given this call for caution, our adjusted odds ratios with confidence intervals that, for the most part, include unity, the potential for uncontrolled confounding, and the uncertainties associated with our traffic exposure metric, we cannot conclude with confidence that the results of our study definitively support an association between traffic exposure, as measured, and LBW, PTD and SGA. We did find associations and so conclude that our results are suggestive of such a relationship and that mobility during pregnancy remains a factor to be considered in similar analyses.

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TABLE 1: DERIVATION OF STUDY BASE

	ALL			COMPARISON-GROUP		
	TOTAL	Non-Movers	Movers	TOTAL	Non-Movers	Movers
Mobility status ascertainable	435,186	302,543	132,643	362,537	253,449	109,088
Mobility status ascertainable + Within 3280 ft	237,228	158,873	78,355	196,554	132,441	64,113
Percent [A]	54.51%	52.51%	59.07%	54.23%	52.26%	58.78%
Mobility status ascertainable + Within 3280 ft. + Complete covariates	126,390	84,181	42,209	106,186	71,127	35,059
Percent [B]	53.28%	52.99%	53.87%	54.02%	53.71%	54.68%

	LBW			PTD			SGA		
	TOTAL	Non-Movers	Movers	TOTAL	Non-Movers	Movers	TOTAL	Non-Movers	Movers
Mobility status ascertainable	6,943	4,538	2,405	18,423	12,627	5,796	42,245	27,794	14,451
Mobility status ascertainable + Within 3280 ft	3,917	2,500	1,417	10,229	6,720	3,509	23,879	15,112	8,767
Percent [A]	56.42%	55.09%	58.92%	55.52%	53.22%	60.54%	56.53%	54.37%	60.67%
Mobility status ascertainable + Within 3280 ft. + Complete covariates	1,953	1,238	715	4,662	3,054	1,608	12,243	7,681	4,562
Percent [B]	49.86%	49.52%	50.46%	45.58%	45.45%	45.83%	51.27%	50.83%	52.04%

A= Percent of those with ascertainable mobility status located within 3280 ft.
B= Percent of those with ascertainable mobility status and within 3280 ft. who had complete covariate data

TABLE 2: % DISTRIBUTION OF MATERNAL CHARACTERISTCS FOR THOSE WITHIN 3280 ft BY INCLUSION/EXCLUSION FROM STUDY BASE

	ALL	Missing Covariate Data	Study Base
Population (N)	*237,228*	*110,838*	*126,390*
Moved during Pregnancy	33.03	32.61	33.40
Lived with 750 feet	27.18	28.05	26.43
Age			
< 15	0.12	0.14	0.09
15-19	8.46	8.52	8.40
20-29	51.94	51.02	52.75
30-34	25.19	25.50	24.91
35-39	11.79	12.10	11.51
40+	2.46	2.60	2.33
Education			
0-8	2.59	2.55	2.63
9-11	10.14	9.72	10.50
HS Diploma / GED	27.93	24.69	30.78
Some College	15.51	13.83	16.99
College Degree	25.30	21.83	28.34
Post Graduate	9.42	7.90	10.76
Race			
White	68.69	60.95	75.48
Black	6.41	7.40	5.54
Asian	11.90	12.98	10.95
Native American /Alaskan Native	1.76	2.10	1.47
Hispanic Race	6.99	7.58	6.48
Other White	0.07	0.08	0.07
Ethnicity: Hispanic	9.20	9.94	8.56
Marital Status: Not Married	26.80	29.62	24.32
Parity: First Birth	43.06	41.14	44.74
Place of Birth			
Washington State	38.14	38.90	37.48
Not US Born	22.57	25.50	20.00
Payor			
Medicaid	27.50	28.75	26.40
Private Insurance	36.22	34.33	37.88
Prenatal Care :Began 1st Trimester	73.18	59.62	85.07
Smoked Cigarettes	12.66	12.36	12.93
Missing Paternal Information	26.21	38.68	15.26
Maternal Medical Risks			
Has at least 1 medical risk	55.67	53.87	57.24
Previous C-Section	2.86	2.47	3.20
Previous Preterm Birth	1.37	1.15	1.56
Diabetes	3.49	2.95	3.96
Hypertension	5.57	4.31	6.67
Herpes	3.11	2.31	3.80
Bleeding	1.58	1.18	1.92
< 1 year since last live birth	1.06	1.07	1.05
< 1year since last fetal death	2.30	1.92	2.63
Occupation			
Housewife	26.34	24.27	28.15
Student or Under 16	4.83	4.66	4.97
Unemployed	4.15	4.66	3.70

TABLE 3a: DESCRIPTION OF THE NEAREST LINE SEGMENT FOR ALL BIRTHS AND COMPARISON-GROUP BY MOBILITY STATUS and OUTCOME

		TOTAL			COMPARISON-GROUP		
		ALL	NON-MOVERS	MOVERS	ALL	NON-MOVERS	MOVERS
	N	126,390	84,181	42,209	106,186	71,127	35,059
	Movers as % of Outcome Category			33.4%			33.0%
DISTANCE TO NEAREST LINE SEGMENT (FEET)	Median	1,380	1,430	1,270	1,380	1,440	1,270
	Mean	1,490	1,520	1,420	1,490	1,530	1,420
	Standard Deviation	910	900	910	910	900	910
TRAFFIC INTENSITY (AADT COUNT) OF NEAREST LINE SEGMENT	Median	33,088	32,432	34,288	32,899	32,148	34,112
	Mean	59,280	58,832	60,173	58,774	58,340	59,655
	Standard Deviation	59,164	60,024	57,401	58,965	59,799	57,227
WEIGHTED TRAFFIC INTENSITY (AADT COUNT) OF NEAREST LINE SEGMENT	Median	32	29	37	30	28	36
	Mean	115	105	136	114	104	134
	Standard Deviation	1,149	1,087	1,263	1,210	1,152	1,321

TABLE 3b: DESCRIPTION OF THE NEAREST LINE SEGMENT FOR LBW, PTD and SGA BIRTHS BY MOBILITY STATUS and OUTCOME

		LBW			PTD			SGA		
		ALL	NON-MOVERS	MOVERS	ALL	NON-MOVERS	MOVERS	ALL	NON-MOVERS	MOVERS
	N	1,953	1,238	715	4,662	3,054	1,608	12,243	7,681	4,562
	Movers as % of Outcome Category			36.6%			34.5%			37.3%
DISTANCE TO NEAREST LINE SEGMENT (FEET)	Median	1,250	1,360	1,150	1,340	1,390	1,250	1,320	1,390	1,210
	Mean	1,420	1,470	1,320	1,470	1,510	1,410	1,450	1,490	1,380
	Standard Deviation	890	900	880	910	900	920	910	900	910
TRAFFIC INTENSITY (AADT COUNT) OF NEAREST LINE SEGMENT	Median	33,667	32,878	35,067	34,865	33,996	36,815	33,969	33,529	35,078
	Mean	60,417	59,516	61,977	62,396	61,600	63,907	62,035	61,609	62,751
	Standard Deviation	894	896	884	909	901	920	907	903	909
WEIGHTED TRAFFIC INTENSITY (AADT COUNT) OF NEAREST LINE SEGMENT	Median	36	33	41	35	32	42	36	33	40
	Mean	108	102	119	125	100	172	128	116	149
	Standard Deviation	495	536	415	787	433	1,200	806	731	919

TABLE 4: DISTRIBUTION OF BIRTHS IN EACH EXPOSURE BUFFER BY OUTCOME and MOBILITY STATUS WITHIN EACH CUMULATIVE BUFFER

	---------------- ALL -------------			---- COMPARISON-GROUP ------		
	TOTAL	NON-Movers	Movers	TOTAL	NON-Movers	Movers
750 ft	33,400	20,963	12,437	27,812	17,580	10,232
(% of Group Study Base)	26.43%	24.90%	29.47%	26.19%	24.72%	29.19%
1640 ft	74,049	47.801	26,248	61,929	40.205	21,724
(% of Group Study Base)	58.59%	56.78%	62.19%	58.32%	56.53%	61.96%
3280 ft (Group Study Base)	126,390	84,181	42,209	106,186	71,127	35,059

BUFFER[A]	------------- TERM LBW --------			---- SPONTANEOUS PTD ----			---------------- SGA ----------------		
	TOTAL	NON-Movers	Movers	TOTAL	NON-Movers	Movers	TOTAL	NON-Movers	Movers
750 ft	557	321	236	1,243	754	489	3,468	2,032	1,436
(% of Group Study Base)	28.52%	25.93%	33.01%	26.66%	24.69%	30.41%	28.33%	26.45%	31.48%
1640 ft	1,223	741	482	2,792	1,783	1,009	7,377	4,475	2,902
(% of Group Study Base)	62.62%	59.85%	67.41%	59.89%	58.38%	62.75%	60.25%	58.26%	63.61%
3280 ft (Group Study Base)	1,953	1,238	715	4,662	3,054	1,608	12,243	7,681	4,562

TABLE 5a: CRUDE AND ADJUSTED ODDS RATIOS AND 95% CONFIDENCE INTERVALS FOR BIRTH RESIDENCE INSIDE VS. BEYOND CUMULATIVE BUFFER ALL BIRTHS COMBINED

BUFFER[A]	LBW		PTD		SGA	
	CRUDE	ADJUSTED [B]	CRUDE	ADJUSTED [B]	CRUDE	ADJUSTED [B]
750 FT	1.12 (1.02-1.24)*	1.05 (0.95-1.16)	1.02 (0.96-1.09)	0.98 (0.92-1.05)	1.11 (1.07-1.16)*	1.04 (1.00-1.09)
1640 FT	1.20 (1.09-1.31)*	1.12 (1.02-1.23)*	1.07(1.01-1.13)*	1.02 (0.96-1.08)	1.08 (1.04-1.13)*	1.02 (0.98-1.06)

A=Buffers are cumulative i.e. those within the 750 ft. buffer are in all the other buffers
B= Adjusted for maternal age, education, race , ethnicity, marital status, parity, prenatal care history, previous pregnancy history, maternal medical risks, smoking history during pregnancy, maternal weight gain, Medicaid payor status and infant sex / not adjusted for mobility status
Comparison Outcome Group consists of births that are neither LBW nor PTD of any subtype nor SGA
* = CI excludes 1

TABLE 5b-5d: CRUDE AND ADJUSTED ODDS RATIOS AND 95% CONFIDENCE INTERVALS FOR BIRTH RESIDENCE INSIDE VS. BEYOND CUMULATIVE BUFFER STRATIFIED BY MOBILITY STATUS

LBW	CRUDE		ADJUSTED	
	NON-MOVERS	MOVERS	NON-MOVERS	MOVERS
750 FT. vs. > 750 FT	1.07(0.94-1.21)	1.20(1.02-1.40)*	1.00(0.88-1.14)	1.12(0.96-1.32)
1640 ft. vs. > 1640 ft.	1.15(1.02-1.29)*	1.27(1.08-1.49)*	1.09(0.97-1.23)	1.18(1.01-1.39)*

PTD	CRUDE		ADJUSTED	
	NON-MOVERS	MOVERS	NON-MOVERS	MOVERS
750 FT. vs. > 750 FT	1.00(0.92-1.09)	1.06(0.95-1.18)	0.96(0.88-1.04)	1.03(0.92-1.15)
1640 ft. vs. > 1640 ft.	1.08(1.00-1.16)	1.03(0.93-1.15)	1.04(0.97-1.12)	0.98(0.89-1.09)

SGA	CRUDE		ADJUSTED	
	NON-MOVERS	MOVERS	NON-MOVERS	MOVERS
750 FT. vs. > 750 FT	1.10(1.04-1.16)*	1.11(1.04-1.19)*	1.03(0.98-1.09)	1.05(0.98-1.13)
1640 ft. vs. > 1640 ft.	1.07(1.02-1.13)*	1.07(1.01-1.14)*	1.02(0.97-1.08)	1.01(0.94-1.08)

A=Buffers are cumulative i.e. those within the 750 ft. buffer are in all the other buffers
B= Adjusted for maternal age, education, race , ethnicity, marital status, parity, prenatal care history, previous pregnancy history, maternal medical risks, smoking history during pregnancy, maternal weight gain, Medicaid payor status and infant sex
Comparison Outcome Group consists of births that are neither LBW nor PTD of any subtype nor SGA
* = CI excludes 1

TABLE 6: MEDIAN TOTAL WEIGHTED TRAFFIC EXPOSURE WITHIN EACH CUMULATIVE BUFFER

BUFFER[A]	-------------------- ALL	--------------		-----COMPARISON-GROUP *----		
	TOTAL	Non-Movers	Movers	TOTAL	Non-Movers	Movers
750 ft	122.75	115.92	134.79	120.89	114.09	133.10
1640 ft	84.48	78.72	94.82	83.21	77.24	94.15
3280 ft	69.10	64.05	80.18	67.76	62.64	78.97

BUFFER[A]	LBW			PTD			SGA		
	TOTAL	Non-Movers	Movers	TOTAL	Non-Movers	Movers	TOTAL	Non-Movers	Movers
750 ft	129.85	129.12	131.05	134.26	125.21	150.59	131.01	122.45	143.67
1640 ft	91.61	89.08	95.88	90.04	82.78	101.67	92.07	86.05	102.20
3280 ft	82.92	77.60	96.41	73.91	69.03	86.60	78.56	72.50	88.98

A=Buffers are cumulative i.e. those within the 750 ft. buffer are in all the other buffers
* Comparison Outcome Group consists of births that are neither LBW nor PTD of any subtype nor SGA

TABLE 7a: CRUDE AND ADJUSTED ODDS RATIOS AND 95% CONFIDENCE INTERVALS FOR QUINTILES OF WEIGHTED TRAFFIC EXPOSURE ALL BIRTHS COMBINED BY CUMULATIVE BUFFER

BUFFER[A]	Quintile Cutpoint	Quintile	LBW		PTD		SGA	
			CRUDE	ADJUSTED[B]	CRUDE	ADJUSTED[B]	CRUDE	ADJUSTED[B]
750 ft	>0	1ST	1.00	1.00	1.00	1.00	1.00	1.00
	45.80	2nd	1.10 (0.84-1.45)	1.02 (0.77-1.34)	1.06 (0.88-1.27)	1.01 (0.83-1.21)	1.11 (0.98-1.24)	1.03 (0.91-1.16)
	86.54	3rd	1.19 (0.91-1.56)	1.09 (0.83-1.43)	1.07 (0.89-1.29)	1.00 (0.83-1.20)	1.20 (1.07-1.35)*	1.11 (0.98-1.24)
	175.31	4th	1.22 (0.93-1.59)	1.09 (0.83-1.44)	1.15 (0.96-1.38)	1.05 (0.87-1.26)	1.16 (1.03-1.30)*	1.06 (0.94-1.19)
	362.36	5th	1.10 (0.84-1.45)	0.94 (0.71-1.25)	1.20 (1.00-1.43)	1.07 (0.89-1.29)	1.23 (1.10-1.38)*	1.08 (0.96-1.22)
1640 ft	>0	1ST	1.00	1.00	1.00	1.00	1.00	1.00
	28.06	2nd	1.09 (0.90-1.31)	0.99 (0.82-1.20)	1.17 (1.04-1.33)*	1.10 (0.97-1.25)	1.07 (0.99-1.15)	0.98 (0.90-1.06)
	60.28	3rd	1.10 (0.91-1.32)	0.97 (0.81-1.18)	1.24 (1.09-1.40)*	1.14 (1.00-1.29)	1.19 (1.11-1.29)*	1.07 (0.99-1.16)
	114.44	4th	1.28 (1.07-1.53)*	1.09 (0.91-1.31)	1.18 (1.04-1.34)*	1.06 (0.94-1.20)	1.17 (1.08-1.26)*	1.01 (0.93-1.10)
	232.75	5th	1.13 (0.94-1.36)	0.95 (0.79-1.14)	1.31 (1.16-1.48)*	1.15 (1.01-1.30)*	1.27 (1.17-1.37)*	1.07 (0.99-1.16)
3280 ft	>0	1ST	1.00	1.00	1.00	1.00	1.00	1.00
	20.57	2nd	0.96 (0.82-1.11)	0.90 (0.78-1.06)	1.10 (1.00-1.21)	1.05 (0.96-1.16)	1.09 (1.03-1.16)*	1.04 (0.98-1.11)
	49.08	3rd	1.15 (0.99-1.33)	1.04 (0.90-1.21)	1.09 (0.99-1.20)	1.01 (0.92-1.11)	1.26 (1.19-1.34)*	1.15 (1.08-1.22)*
	96.32	4th	1.30 (1.12-1.49)*	1.12 (0.97-1.30)	1.18 (1.08-1.30)*	1.07 (0.97-1.17)	1.26 (1.18-1.34)*	1.09 (1.02-1.16)*
	198.86	5th	1.34 (1.16-1.54)*	1.12 (0.96-1.29)	1.24 (1.13-1.36)*	1.08 (0.98-1.19)	1.36 (1.28-1.45)*	1.13 (1.06-1.20)*

A=Buffers are cumulative i.e. those within the 750 ft. buffer are in all the other buffers
B= Adjusted for maternal age, education, race , ethnicity, marital status, parity, prenatal care history, previous pregnancy history, maternal medical risks, smoking history during pregnancy, maternal weight gain, Medicaid payor status and infant sex
Comparison Outcome Group consists of births that are neither LBW nor PTD of any subtype nor SGA
* = CI excludes 1

TABLE 7b: CRUDE AND ADJUSTED ODDS RATIOS AND 95% CONFIDENCE INTERVALS FOR QUINTILES OF WEIGHTED TRAFFIC EXPOSURE FOR LBW STRATIFIED BY MOBILITY STATUS

LBW			CRUDE		ADJUSTED [B]	
BUFFER[A]	Quintile Cutpoint	Quintile	NON-MOVERS	MOVERS	NON-MOVERS	MOVERS
750 ft	>0	1ST	1.00	1.00	1.00	1.00
750 ft	45.80	2nd	1.41(0.99-2.02)	0.75(0.49-1.14)	1.27(0.88-1.82)	0.75(0.48-1.16)
750 ft	86.54	3rd	1.42(0.99-2.03)	0.91(0.61-1.36)	1.27(0.88-1.83)	0.89(0.59-1.36)
750 ft	175.31	4th	1.39(0.97-1.99)	0.98(0.66-1.46)	1.24(0.86-1.79)	0.91(0.60-1.37)
750 ft	362.36	5th	1.32(0.91-1.91)	0.82(0.54-1.23)	1.14(0.78-1.67)	0.72(0.47-1.10)
1640 ft	>0	1ST	1.00	1.00	1.00	1.00
1640 ft	28.06	2nd	1.02(0.81-1.29)	1.14(0.84-1.53)	0.94(0.74-1.19)	1.06(0.79-1.44)
1640 ft	60.28	3rd	1.18(0.93-1.48)	0.93(0.68-1.26)	1.05(0.83-1.33)	0.86(0.63-1.18)
1640 ft	114.44	4th	1.39(1.11-1.73)*	1.07(0.80-1.44)	1.20(0.95-1.50)	0.93(0.69-1.26)
1640 ft	232.75	5th	1.15(0.91-1.45)	1.04(0.77-1.40)	0.99(0.78-1.26)	0.88(0.65-1.19)
3280 ft	>0	1ST	1.00	1.00	1.00	1.00
3280 ft	20.57	2nd	0.87(0.73-1.05)	1.15(0.87-1.51)	0.84(0.70-1.01)	1.06(0.81-1.40)
3280 ft	49.08	3rd	1.07(0.90-1.28)	1.31(1.00-1.70)	0.99(0.83-1.18)	1.19(0.91-1.56)
3280 ft	96.32	4th	1.21(1.01-1.43)*	1.48(1.14-1.90)*	1.06(0.89-1.27)	1.28(0.99-1.66)
3280 ft	198.86	5th	1.25(1.05-1.49)*	1.52(1.18-1.95)*	1.07(0.89-1.28)	1.24(0.96-1.61)

TABLE 7c: CRUDE AND ADJUSTED ODDS RATIOS AND 95% CONFIDENCE INTERVALS FOR QUINTILES OF WEIGHTED TRAFFIC EXPOSURE FOR PTD STRATIFIED BY MOBILITY STATUS

PTD			CRUDE		ADJUSTED [B]	
BUFFER[A]	Quintile Cutpoint	Quintile	NON-MOVERS	MOVERS	NON-MOVERS	MOVERS
750 ft	>0	1ST	1.00	1.00	1.00	1.00
750 ft	45.80	2nd	1.15(0.91-1.45)	0.91(0.67-1.23)	1.07 (0.85-1.36)	0.89 (0.65-1.21)
750 ft	86.54	3rd	1.16(0.92-1.46)	0.92(0.68-1.25)	1.06 (0.84-1.34)	0.88 (0.64-1.19)
750 ft	175.31	4th	1.16(0.92-1.46)	1.10(0.83-1.47)	1.04 (0.82-1.32)	1.03 (0.77-1.39)
750 ft	362.36	5th	1.25(0.99-1.57)	1.09(0.81-1.45)	1.09 (0.86-1.38)	1.02 (0.76-1.36)
1640 ft	>0	1ST	1.00	1.00	1.00	1.00
1640 ft	28.06	2nd	1.25(1.08-1.45)*	1.02(0.82-1.28)	1.19 (1.03-1.39)*	0.94 (0.75-1.18)
1640 ft	60.28	3rd	1.20(1.03-1.40)*	1.28(1.04-1.59)*	1.11 (0.95-1.29)	1.17 (0.94-1.45)
1640 ft	114.44	4th	1.19(1.02-1.39)*	1.15(0.93-1.43)	1.09 (0.93-1.27)	1.01 (0.81-1.25)
1640 ft	232.75	5th	1.32(1.13-1.53)*	1.26(1.02-1.56)*	1.18 (1.01-1.37)*	1.10 (0.89-1.36)
3280 ft	>0	1ST	1.00	1.00	1.00	1.00
3280 ft	20.57	2nd	1.09(0.98-1.22)	1.11(0.93-1.32)	1.07 (0.95-1.20)	1.02(0.86-1.22)
3280 ft	49.08	3rd	1.07(0.95-1.20)	1.12(0.94-1.33)	1.00 (0.89-1.13)	1.02(0.86-1.22)
3280 ft	96.32	4th	1.16(1.04-1.30)*	1.21(1.02-1.43)*	1.07 (0.95-1.20)	1.07(0.90-1.27)
3280 ft	198.86	5th	1.22(1.09-1.36)*	1.26(1.07-1.49)*	1.08 (0.96-1.22)	1.08(0.92-1.28)

TABLE 7d: CRUDE AND ADJUSTED ODDS RATIOS AND 95% CONFIDENCE INTERVALS FOR QUINTILES OF WEIGHTED TRAFFIC EXPOSURE FOR SGA STRATIFIED BY MOBILITY STATUS

SGA			CRUDE		ADJUSTED [B]	
BUFFER[A]	Quintile Cutpoint	Quintile	NON-MOVERS	MOVERS	NON-MOVERS	MOVERS
750 ft	>0	1ST	1.00	1.00	1.00	1.00
750 ft	45.80	2nd	1.15(0.99-1.33)	1.01(0.84-1.22)	1.08(0.93-1.25)	0.96(0.79-1.16)
750 ft	86.54	3rd	1.26(1.09-1.45)*	1.10(0.91-1.31)	1.16(1.00-1.35)	1.03(0.85-1.24)
750 ft	175.31	4th	1.17(1.01-1.36)*	1.10(0.92-1.32)	1.08(0.92-1.25)	1.02(0.84-1.23)
750 ft	362.36	5th	1.25(1.08-1.45)*	1.16(0.97-1.38)	1.10(0.94-1.28)	1.05(0.87-1.26)
1640 ft	>0	1ST	1.00	1.00	1.00	1.00
1640 ft	28.06	2nd	1.09(0.98-1.20)	1.00(0.87-1.14)	1.01(0.92-1.12)	0.92(0.80-1.05)
1640 ft	60.28	3rd	1.22(1.11-1.34)*	1.11(0.97-1.26)	1.10(0.99-1.22)	1.01(0.88-1.16)
1640 ft	114.44	4th	1.19(1.08-1.32)*	1.08(0.95-1.23)	1.06(0.95-1.17)	0.94(0.82-1.07)
1640 ft	232.75	5th	1.23(1.12-1.36)*	1.24(1.09-1.41)*	1.06(0.96-1.18)	1.05(0.92-1.20)
3280 ft	>0	1ST	1.00	1.00	1.00	1.00
3280 ft	20.57	2nd	1.05(0.97-1.13)	1.17(1.05-1.31)*	1.01(0.94-1.09)	1.10(0.98-1.23)
3280 ft	49.08	3rd	1.23(1.14-1.33)*	1.30(1.17-1.45)*	1.13(1.05-1.22)*	1.18(1.06-1.32)*
3280 ft	96.32	4th	1.22(1.14-1.32)*	1.28(1.15-1.42)*	1.08(1.00-1.17)	1.11(0.99-1.24)
3280 ft	198.86	5th	1.30(1.20-1.40)*	1.42(1.28-1.58)*	1.11(1.02-1.19)*	1.18(1.06-1.31)*

A=Buffers are cumulative i.e. those within the 750 ft. buffer are in all the other buffers
B= Adjusted for maternal age, education, race , ethnicity, marital status, parity, prenatal care history, previous pregnancy history, maternal medical risks, smoking history during pregnancy, maternal weight gain, Medicaid payor status and infant sex / not adjusted for mobility status
Comparison Outcome Group consists of births that are neither LBW nor PTD of any subtype nor SGA
* = CI excludes 1

TABLE 8: REPORTED ADJUSTED ASSOCIATIONS BETWEEN DISTANCE TO ROADWAY AND ADVERSE BIRTH OUTCOMES

	Yang (30)	**Wilhelm (32)**[A]	**Brauer (21)**		**Genereux (31)**[D]	This Study[E]	
Study Type	Cohort	Case Control	Cohort		Cohort	Cohort	
Dates	1992-1997	1994-1996	1999-2002		1997-2001	1994-2004	
Distance Buffer	1640 ft. (500m)	750 ft.	492 ft (150m)		656 ft (200m)	750 ft.	1640 ft
Road type	Major Freeway	Major Freeway	Major Highway[B]	Major Road[C]	Highway	Major Highways & Major Roads Combined	Major Highways & Major Roads Combined
OR_{LBW}	--	1.02 (0.91–1.14)	1.01 (0.76-1.33)	0.94 (0.79-1.10)	1.17 (1.04-1.33)	1.05 (0.95-1.16)	1.12 (1.02-1.23)
OR_{PTD}	1.30 (1.03-1.65)	1.01 (0.90–1.13)	-	--	1.14 (1.02-1.27)	0.98 (0.92-1.05)	1.02 (0.96-1.08)
OR_{SGA}	--	0.96 (0.89–1.02)	0.93 (0.83-1.03)	1.04 (0.96-1.11)	1.06 (0.96-1.17)	1.04 (1.00-1.09)	1.02 (0.98-1.06)

A= Wilhelm & Ritz, Table 3: ORs Adjusted for: gestational week, gestational week squared, infant sex, prenatal care, parity, time since last live birth, maternal age, education, race, previous LBW or PTD birth, year of birth, birth season, Annual average concentrations of CO, PM_{10},NO_2, O3

B= Brauer et al, Table 6: Adjusted for infant sex, First Nations status, parity, maternal age, maternal smoking during pregnancy, month–year of birth, income (quintile-census), maternal education (quartile-census, Major =expressway: 114,000 vehicles/ day; principal highway: 21,000 vehicles/day, Major road; secondary highway: 18,000 vehicles/day; 15,000 vehicles/day).

C= Brauer et al. Table 5: Adjusted for infant sex, First Nations status, parity, maternal age, maternal smoking during pregnancy, month–year of birth, income (quintile-census), maternal education (quartile-census).: major highway: expressway: 114,000 vehicles/day; principal highway: 21,000 vehicles/day)., Major Road: secondary highway: 18,000 vehicles/day; major road: 15,000 vehicles/day).

D = Genereux et al Table 3: Adjusted for maternal age, civil (legally marital) status, country of birth, history of prior stillbirth, birth order, newborn sex, year of birth
Highway = controlled access expressways

E = Movers and Non-movers Combined : Table 5a

TABLE 9a: COMPARISON OF STUDY RESULTS FOR QUINTILES OF WEIGHTED EXPOSURE FOR PTD WITHIN 750 ft. BUFFER

PRE-TERM BIRTH				
	Crude Associations		**Adjusted Associations**	
	Brown et al [a]	Wilhelm & Ritz [b]	Brown et al [c]	Wilhelm & Ritz [d]
Quintile 1		1.00		1.00
Quintile 2	1.06(0.88-1.27)	1.00(0.94-1.07)	1.01(0.83-1.21)	0.99(0.93-1.05)
Quintile 3	1.07(0.89-1.29)	1.05(0.98-1.11)	1.00(0.83-1.20)	1.02(0.96-1.09)
Quintile 4	1.15(0.96-1.38)	1.10(1.04-1.17)	1.05(0.87-1.26)	1.07(1.01-1.13)
Quintile 5	1.20(1.00-1.43)	1.11(1.04-1.18)	1.07(0.89-1.29)	1.08(1.01-1.15)

a = Table 7b:Quintiles of Exposure: Odds Ratios
b = Table 4, Wilhelm & Ritz Single Parameter Models; RR ("ORs converted to RR using case control sampling fractions to adjust intercept values")
c = Table 7b:Adjusted for maternal age, education, race , ethnicity, marital status, parity, prenatal care history, previous pregnancy history, maternal medical risks, smoking history during pregnancy, maternal weight gain, Medicaid payor status and infant sex (not mobility)
d = Table 4, Wilhelm & Ritz RR: Models adjusting for the following: infant sex, maternal age, race, education, time since last live birth, parity, level of prenatal care year of analysis, birth season, background concentrations + freeway indicator ("ORs converted to RR using case control sampling fractions to adjust intercept values")

TABLE 9b: COMPARISON OF STUDY RESULTS FOR QUINTILES OF WEIGHTED TRAFFIC EXPOSURE FOR LBW WITHIN 750 ft. BUFFER

TERM LBW				
	Crude Associations		**Adjusted Associations**	
	Brown et al [a]	Wilhelm & Ritz [b]	Brown et al [c]	Wilhelm & Ritz [d]
Quintile 1	1.00	1.00		1.00
Quintile 2	1.10(0.84-1.45)	1.13(1.02-1.27)	1.02(0.77-1.34)	1.11(0.99-1.25)
Quintile 3	1.19(0.91-1.56)	1.16(1.04-1.29)	1.09(0.83-1.43)	1.16(1.03-1.30)
Quintile 4	1.22(0.93-1.59)	1.18(1.05-1.31)	1.09(0.83-1.44)	1.15(1.02-1.29)
Quintile 5	1.10(0.84-1.45)	1.16(1.04-1.30)	0.94(0.71-1.25)	1.11(0.99-1.26)

a = Table 7b:Quintiles of Exposure: Odds Ratios
b = Table 4, Wilhelm & Ritz Single Parameter Models; RR ("ORs converted to RR using case control sampling fractions to adjust intercept values")
c = Table 7b: Adjusted for maternal age, education, race , ethnicity, marital status, parity, prenatal care history, previous pregnancy history, maternal medical risks, smoking history during pregnancy, maternal weight gain, Medicaid payor status and infant sex (NOT for mobility)
d = Table 4, Wilhelm & Ritz RR: Models adjusting for the following: infant, maternal age, race, education, time since last live birth, parity, level of prenatal care year of analysis, birth season, background concentrations + freeway indicator ("ORs converted to RR using case control sampling fractions to adjust intercept values")

TABLE 10: ADJUSTED ODDS RATIOS AND 95% CONFIDENCE INTERVALS FOR QUINTILES OF WEIGHTED TRAFFIC EXPOSURE ALL BIRTHS COMBINED and NON-MOVERS BY CUMULATIVE BUFFER

BUFFER[A]	Quintile Cutpoint	Quintile	LBW		PTD		SGA	
			NON-MOVERS	ALL BIRTHS	NON-MOVERS	ALL BIRTHS	NON-MOVERS	ALL BIRTHS
750 ft	>0	1ST	1.00	1.00	1.00	1.00	1.00	1.00
	45.80	2nd	1.27 (0.88-1.82)	1.02 (0.77-1.34)	1.07 (0.85-1.36)	1.01 (0.83-1.21)	1.08 (0.93-1.25)	1.03 (0.91-1.16)
	86.54	3rd	1.27 (0.88-1.83)	1.09 (0.83-1.43)	1.06 (0.84-1.34)	1.00 (0.83-1.20)	1.16 (1.00-1.35)	1.11 (0.98-1.24)
	175.31	4th	1.24 (0.86-1.79)	1.09 (0.83-1.44)	1.04 (0.82-1.32)	1.05 (0.87-1.26)	1.08 (0.92-1.25)	1.06 (0.94-1.19)
	362.36	5th	1.14 (0.78-1.67)	0.94 (0.71-1.25)	1.09 (0.86-1.38)	1.07 (0.89-1.29)	1.10 (0.94-1.28)	1.08 (0.96-1.22)
1640 ft	>0	1ST	1.00	1.00	1.00	1.00	1.00	1.00
	28.06	2nd	0.94 (0.74-1.19)	0.99 (0.82-1.20)	1.19 (1.03-1.39)*	1.10 (0.97-1.25)	1.01 (0.92-1.12)	0.98 (0.90-1.06)
	60.28	3rd	1.05 (0.83-1.33)	0.97 (0.81-1.18)	1.11 (0.95-1.29)	1.14 (1.00-1.29)	1.10 (0.99-1.22)	1.07 (0.99-1.16)
	114.44	4th	1.20 (0.95-1.50)	1.09 (0.91-1.31)	1.09 (0.93-1.27)	1.06 (0.94-1.20)	1.06 (0.95-1.17)	1.01 (0.93-1.10)
	232.75	5th	0.99 (0.78-1.26)	0.95 (0.79-1.14)	1.18 (1.01-1.37)*	1.15 (1.01-1.30)*	1.06 (0.96-1.18)	1.07 (0.99-1.16)
3280 ft	>0	1ST	1.00	1.00	1.00	1.00	1.00	1.00
	20.57	2nd	0.84 (0.70-1.01)	0.90 (0.78-1.06)	1.07 (0.95-1.20)	1.05 (0.96-1.16)	1.01 (0.94-1.09)	1.04 (0.98-1.11)
	49.08	3rd	0.99 (0.83-1.18)	1.04 (0.90-1.21)	1.00 (0.89-1.13)	1.01 (0.92-1.11)	1.13 (1.05-1.22)*	1.15 (1.08-1.22)*
	96.32	4th	1.06 (0.89-1.27)	1.12 (0.97-1.30)	1.07 (0.95-1.20)	1.07 (0.97-1.17)	1.08 (1.00-1.17)	1.09 (1.02-1.16)*
	198.86	5th	1.07 (0.89-1.28)	1.12 (0.96-1.29)	1.08 (0.96-1.22)	1.08 (0.98-1.19)	1.11 (1.02-1.19)*	1.13 (1.06-1.20)*

A=Buffers are cumulative i.e. those within the 750 ft. buffer are in all the other buffers
B= Adjusted for maternal age, education, race , ethnicity, marital status, parity, prenatal care history, previous pregnancy history, maternal medical risks, smoking history during pregnancy, maternal weight gain, Medicaid payor status and infant sex
Comparison Outcome Group consists of births that are neither LBW nor PTD of any subtype nor SGA
* = CI excludes 1

Figure 1a. DEVELOPMENT OF ANALYTIC STUDY BASE

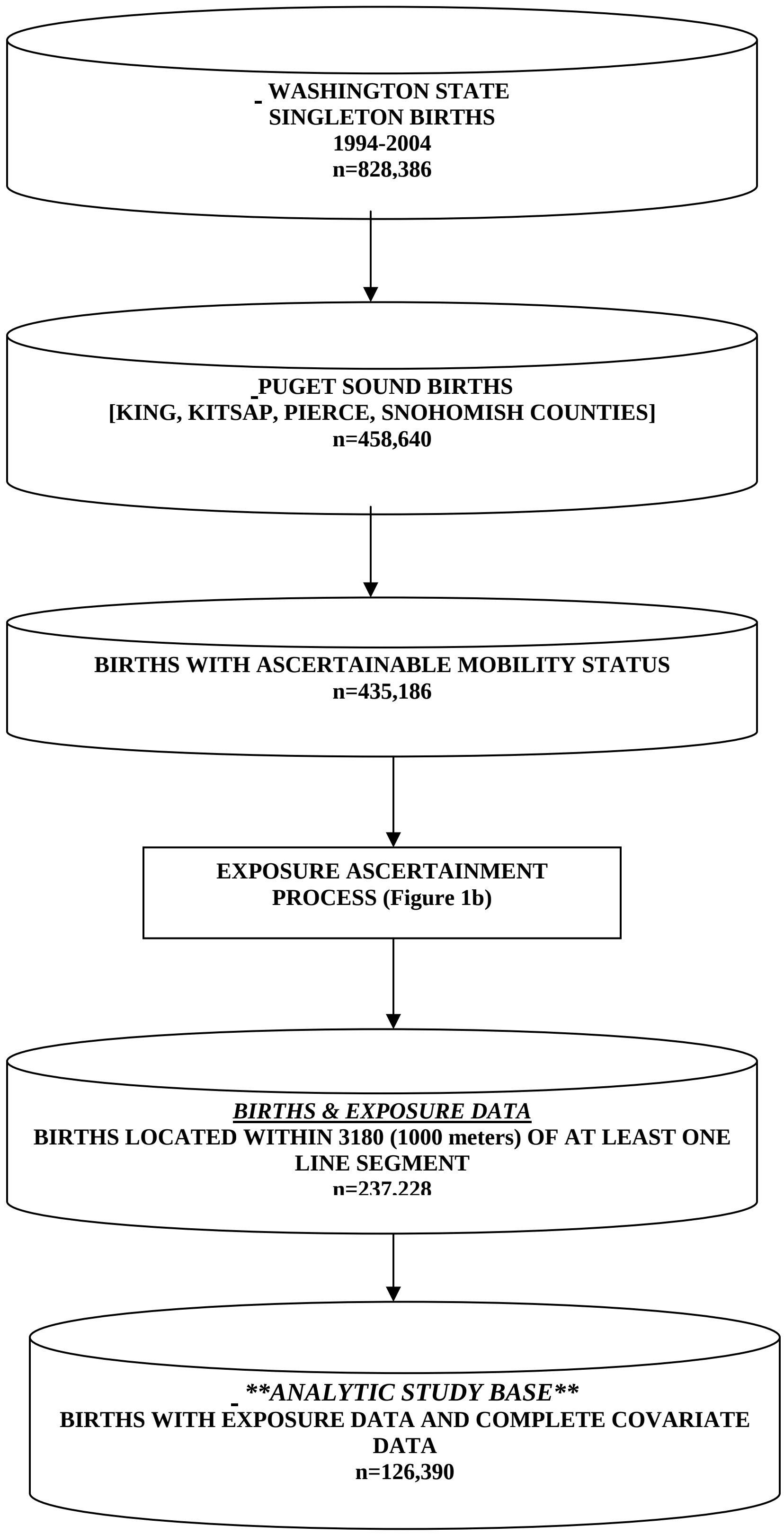


Figure1b. DEVELOPMENT OF EXPOSURE DATA

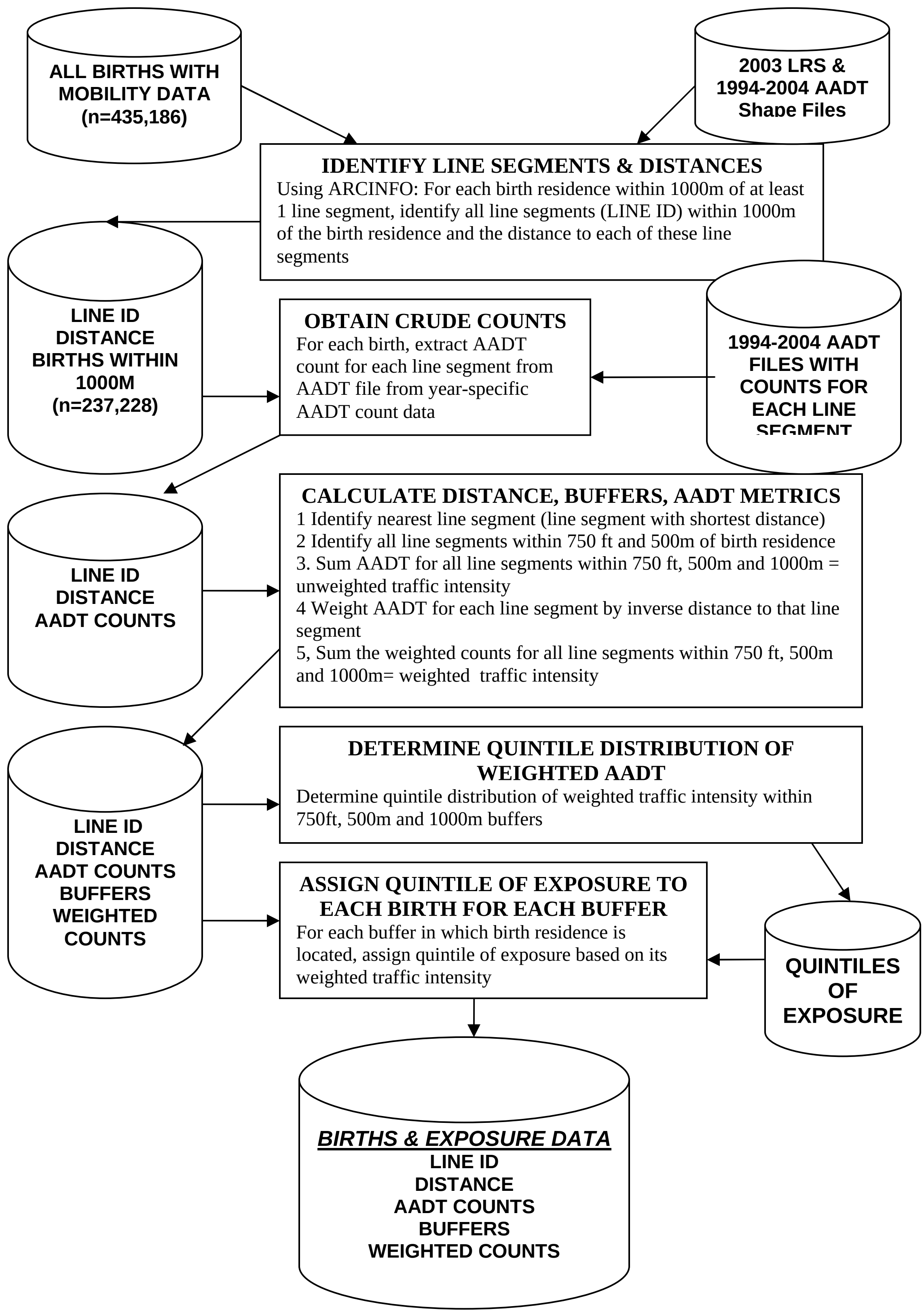


Figure 1c: Analysis Flow: Primary Analyses

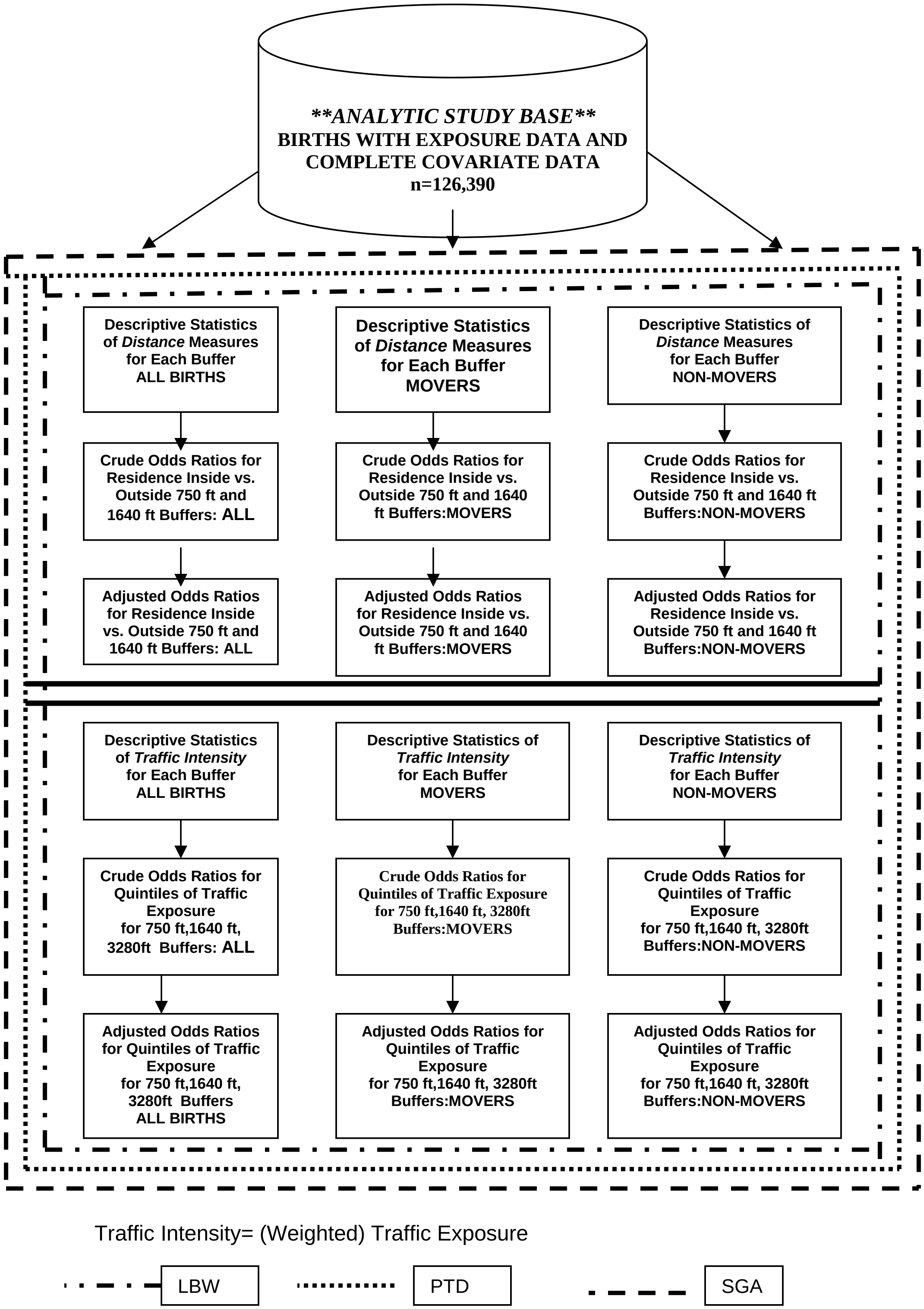
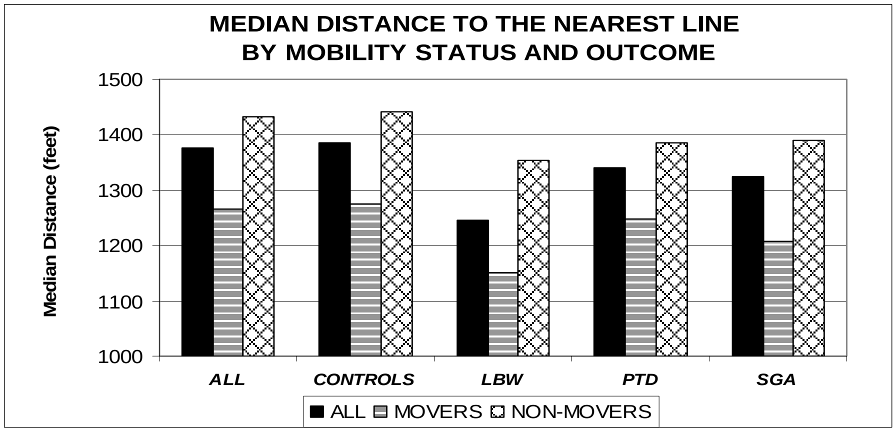
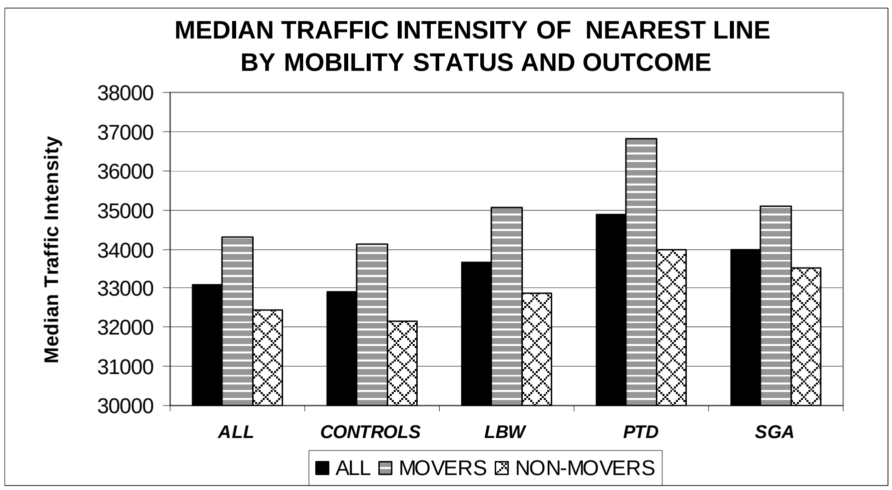


FIGURE 2a: DISTANCE TO NEAREST LINE SEGMENT



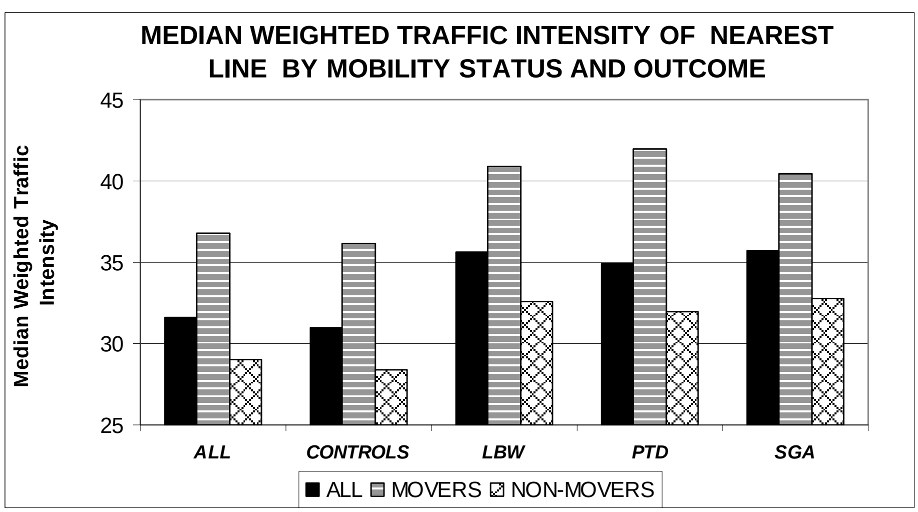
- Controls = Comparison Group

FIGURE 2b: UNWEIGHTED TRAFFIC OF NEAREST LINE SEGMENT



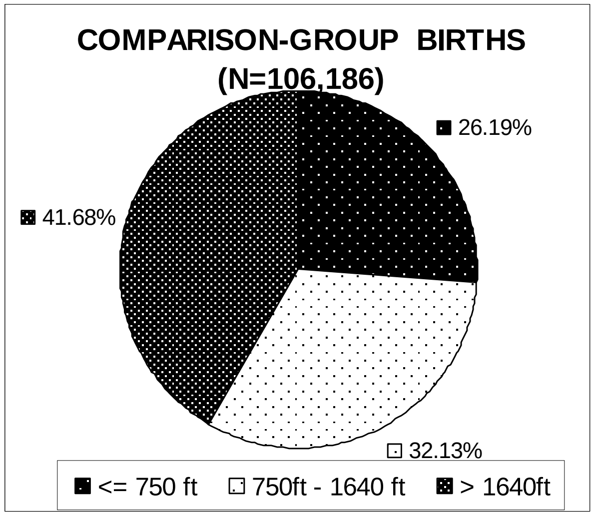
* Controls = Comparison Group

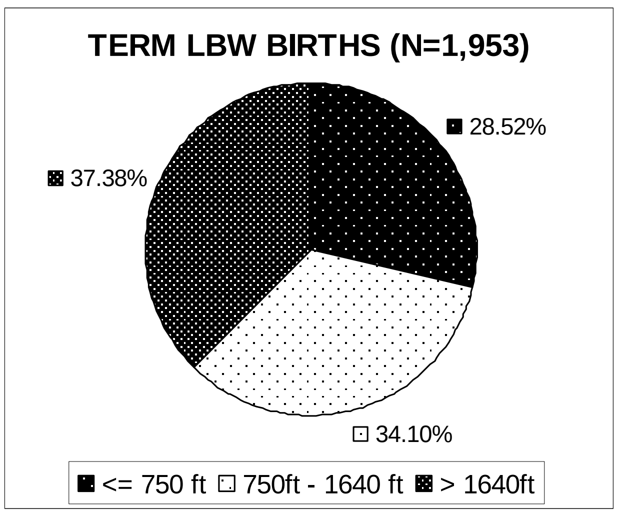
FIGURE 2c: WEIGHTED TRAFFIC INTENSITY OF NEAREST LINE SEGMENT



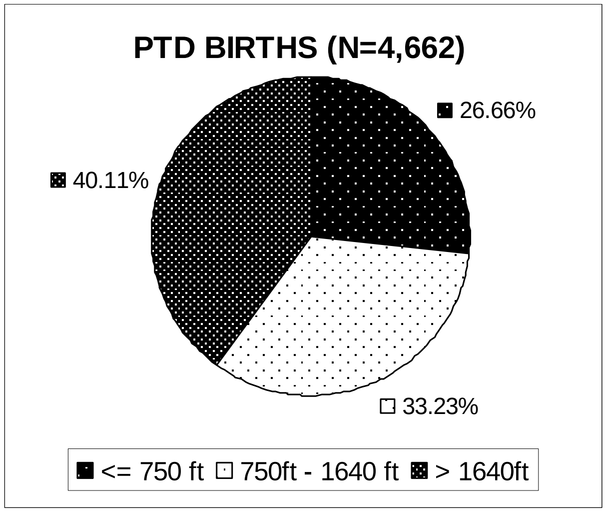
* Controls = Comparison Group

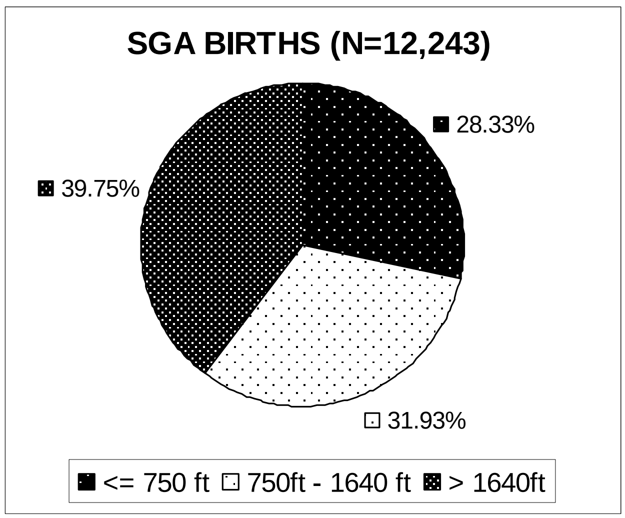
FIGURES 3a-3b: PERCENTAGE OF COMPARISON-GROUP & LBW BIRTHS LOCATED AT SPECIFIED DISTANCES FROM THE NEAREST LINE SEGMENT



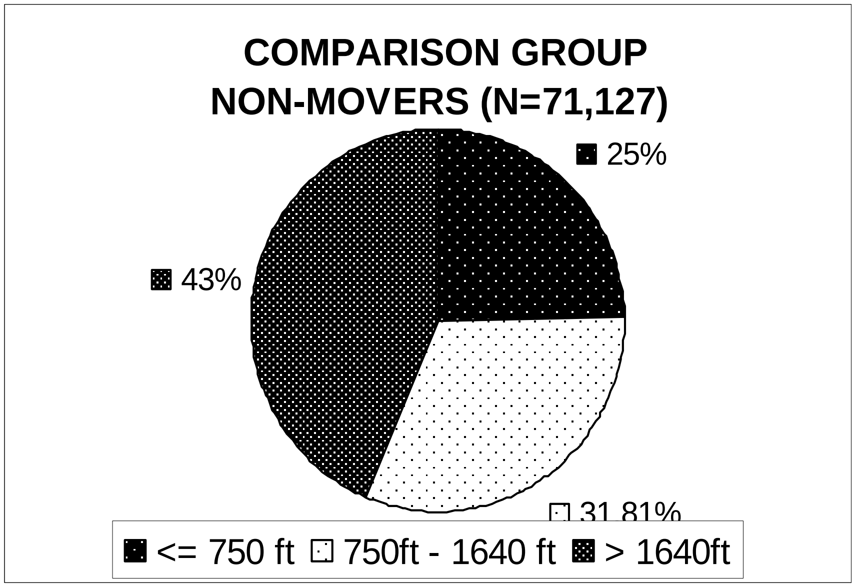


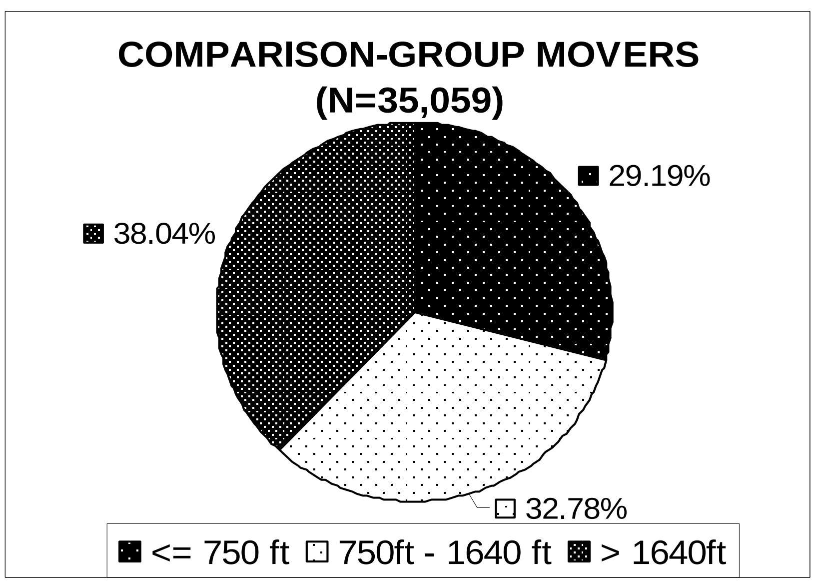
FIGURES 3c-3d: PERCENTAGE OF PTD & SGA BIRTHS LOCATED AT SPECIFIED DISTANCES FROM THE NEAREST LINE SEGMENT



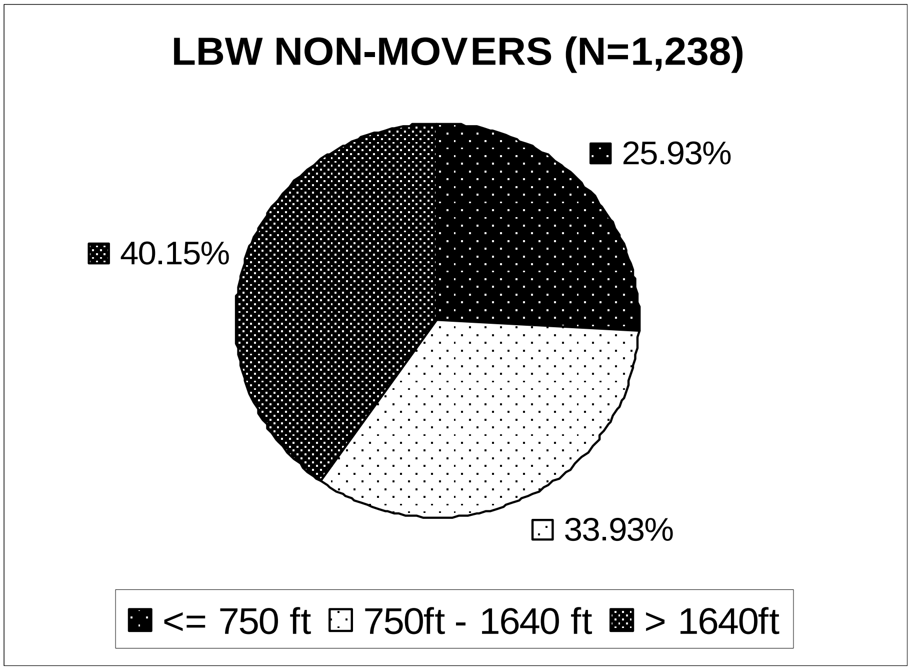


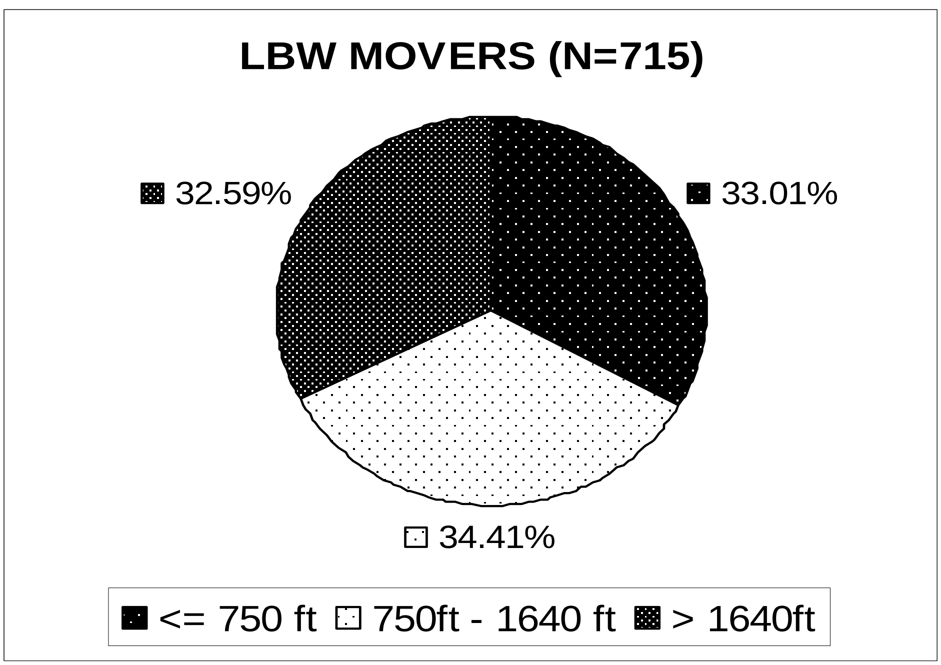
FIGURES 3e-3f: PERCENTAGE OF COMPARISON GROUP BIRTHS LOCATED AT SPECIFIED DISTANCES FROM THE NEAREST LINE SEGMENT BY MOBILITY STATUS



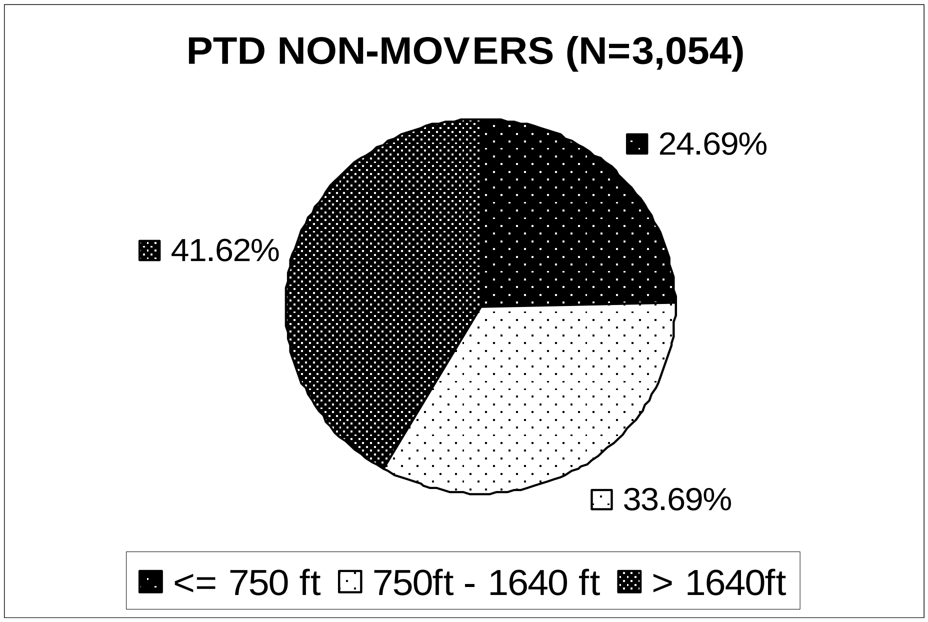


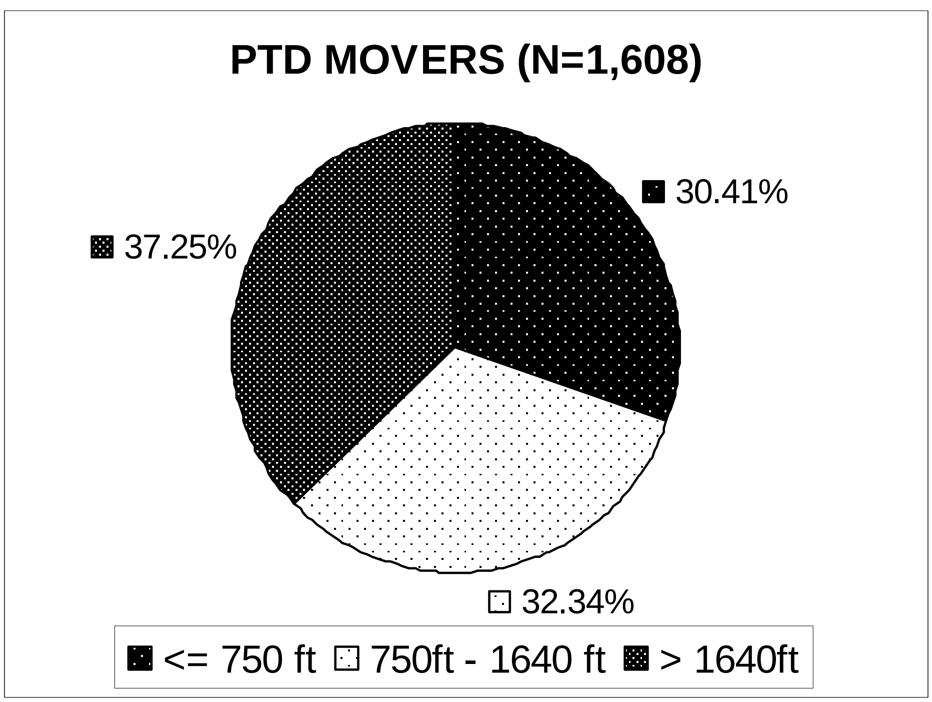
FIGURES 3g-3h: PERCENTAGE OF LBW BIRTHS LOCATED AT SPECIFIED DISTANCES FROM THE NEAREST LINE SEGMENT BY MOBILITY STATUS



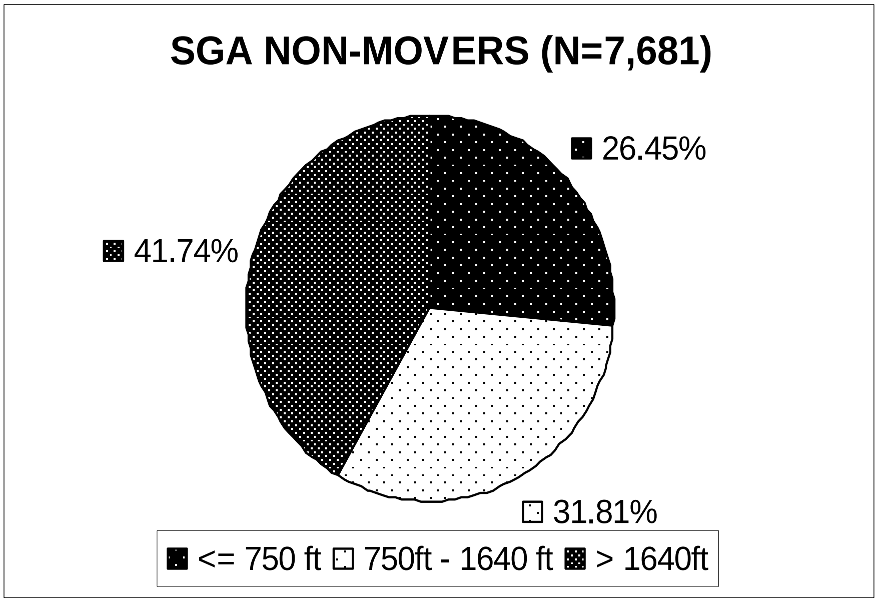


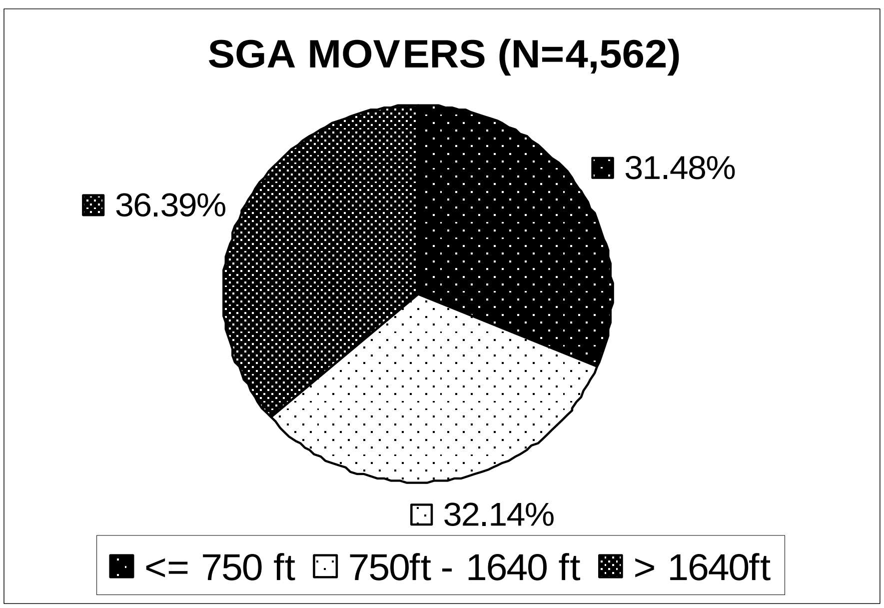
FIGURES 3i-3j: PERCENTAGE OF LBW BIRTHS LOCATED AT SPECIFIED DISTANCES FROM THE NEAREST LINE SEGMENT BY MOBILITY STATUS



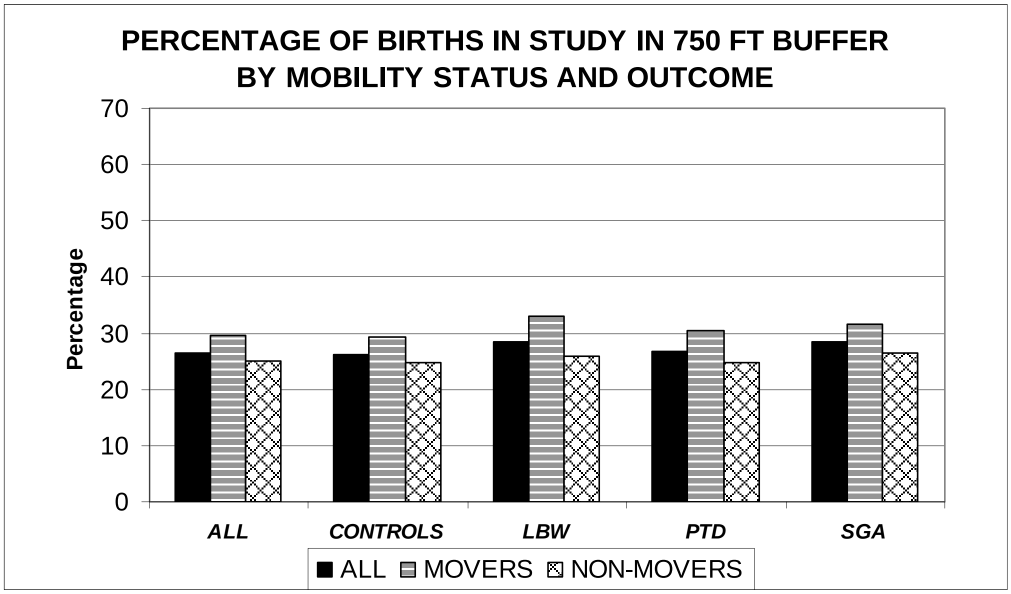


FIGURES 3k-3l: PERCENTAGE OF SGA BIRTHS LOCATED AT SPECIFIED DISTANCES FROM THE NEAREST LINE SEGMENT BY MOBILITY STATUS

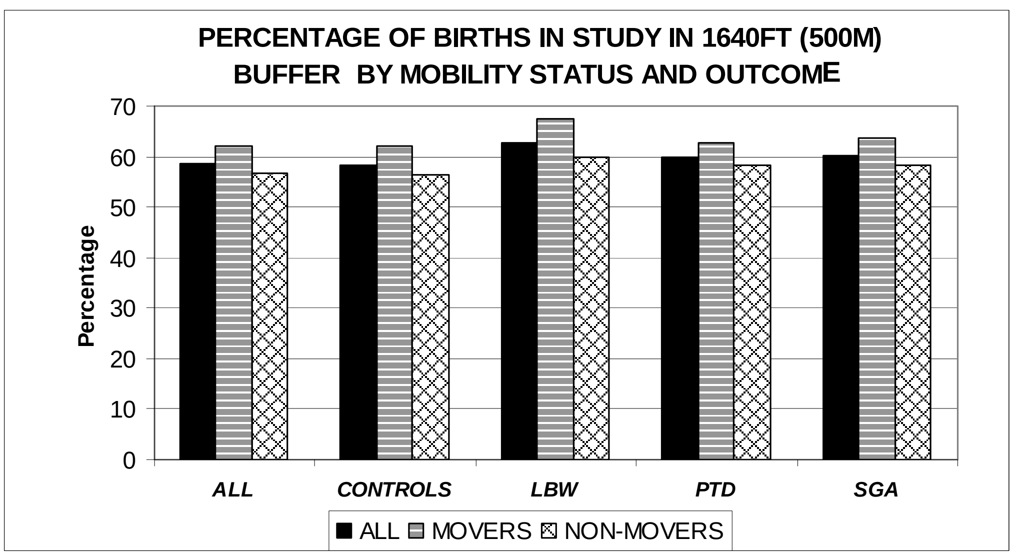




Figures 4a-4b: DISTRIBUTION OF BIRTHS IN STUDY BASE RESIDENT IN 750 ft. AND 1640 ft. CUMULATIVE BUFFERS BY OUTCOME AND MOBILITY STATUS

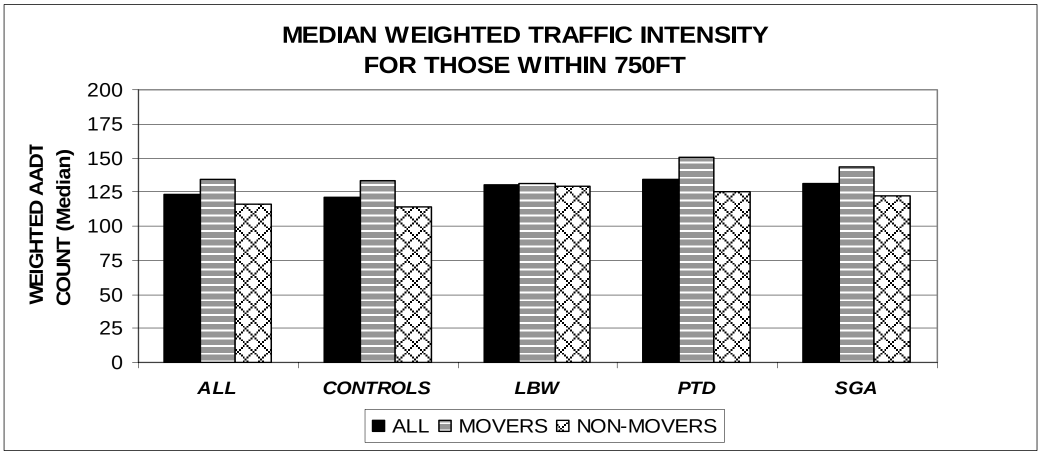


* Controls = Comparison Group

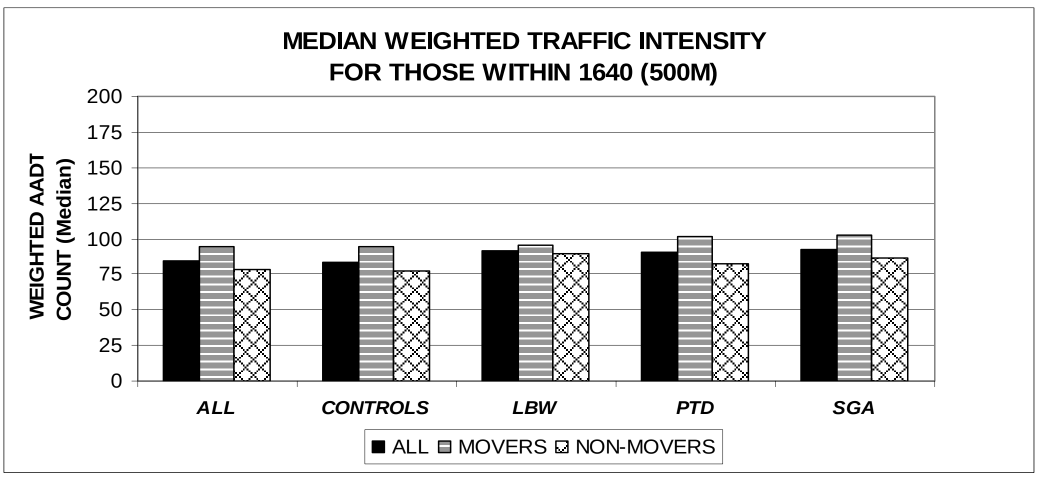


* Controls = Comparison Group

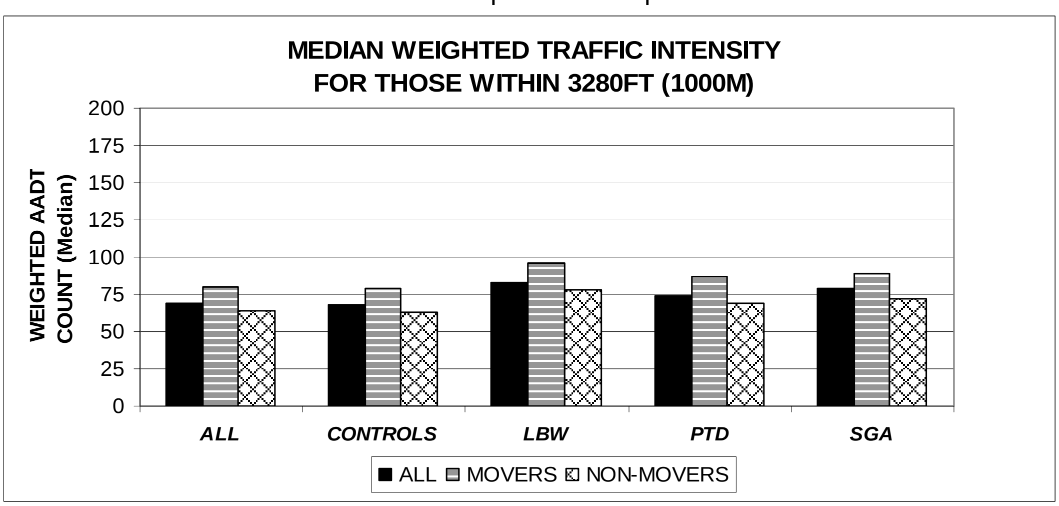
Figures 5a-5c: MEDIAN TOTAL WEIGHTED TRAFFIC INTENSITY BY OUTCOME AND MOBILITY STATUS WITHIN CUMULATIVE EXPOSURE BUFFERS



* Controls = Comparison Group

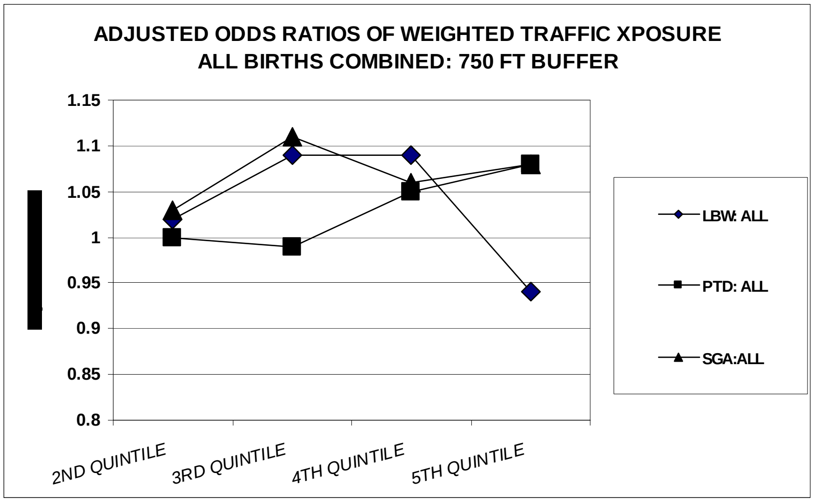


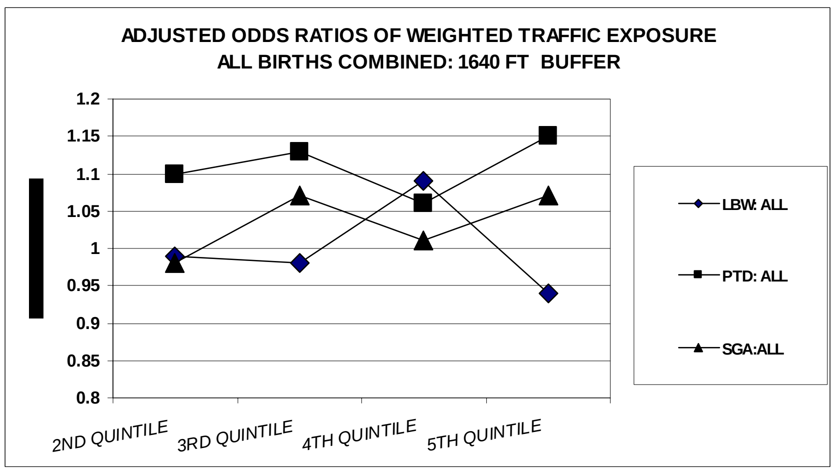
* Controls = Comparison Group

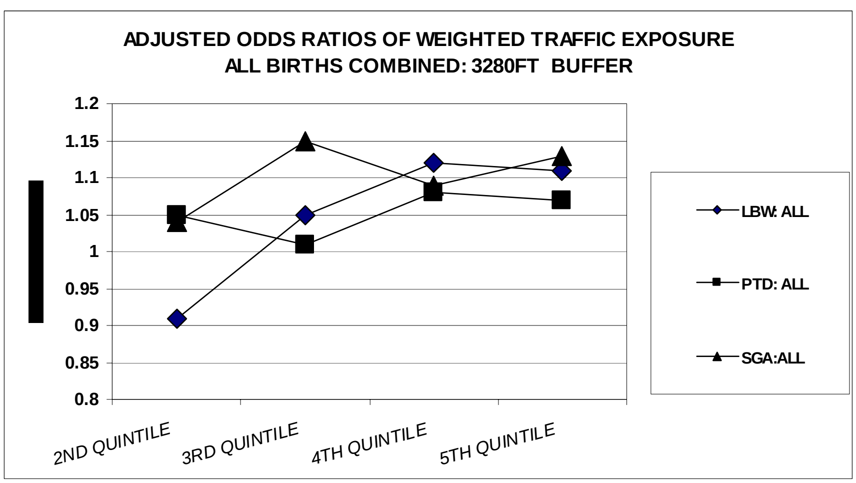


* Controls = Comparison Group

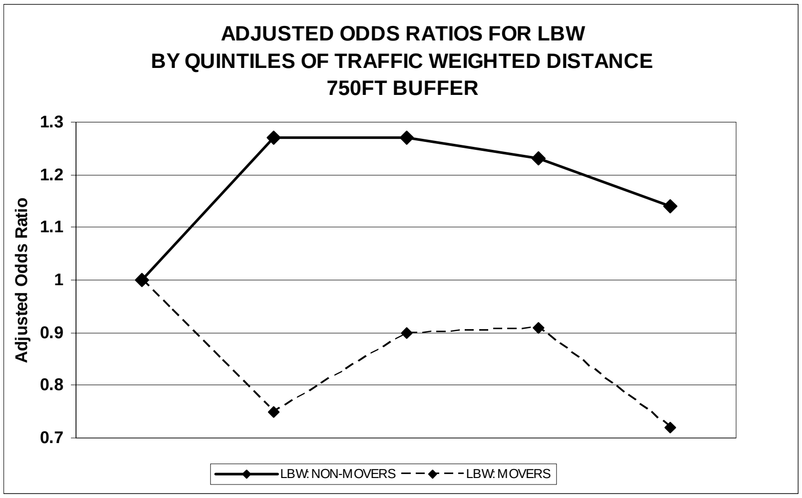
FIGURE 6a-6c: ADJUSTED ODDS RATIOS OF WEIGHTED TRAFFIC EXPOSURE FOR NESTED DISTANCE BUFFERS: ALL BIRTHS COMBINED

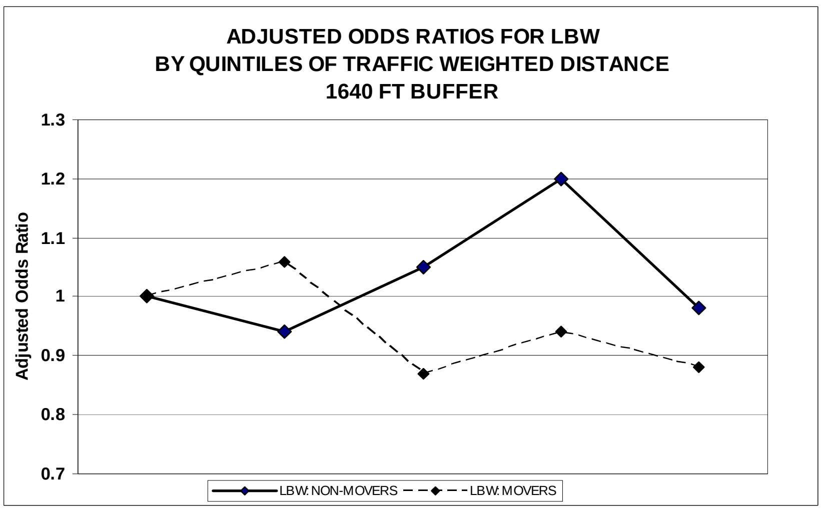






7a-7c: COMPARISON OF MOVERS AND NON-MOVERS IN THREE NESTED DISTANCE FROM ROADWAY BUFFERS ADJUSTED ODDS RATIOS FOR LBW VS. COMPARISON-GROUP BY QUINTILE OF TRAFFIC WEIGHTED DISTANCE





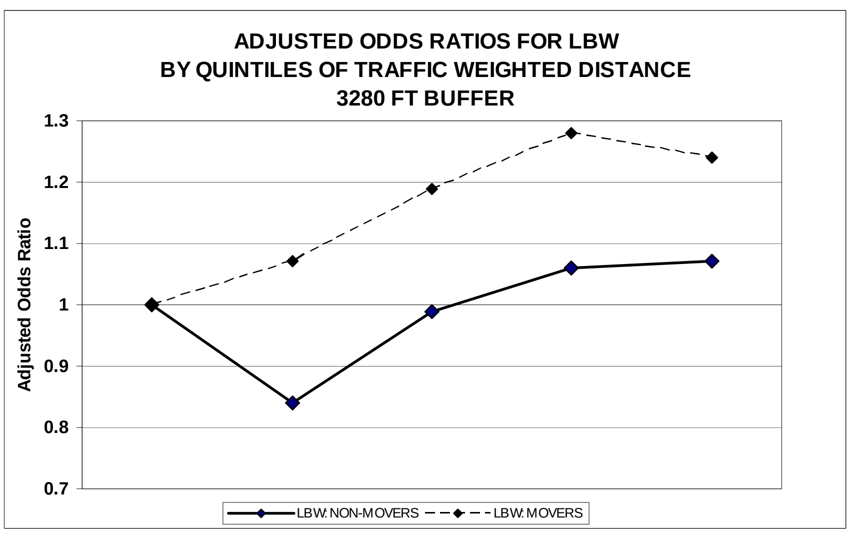
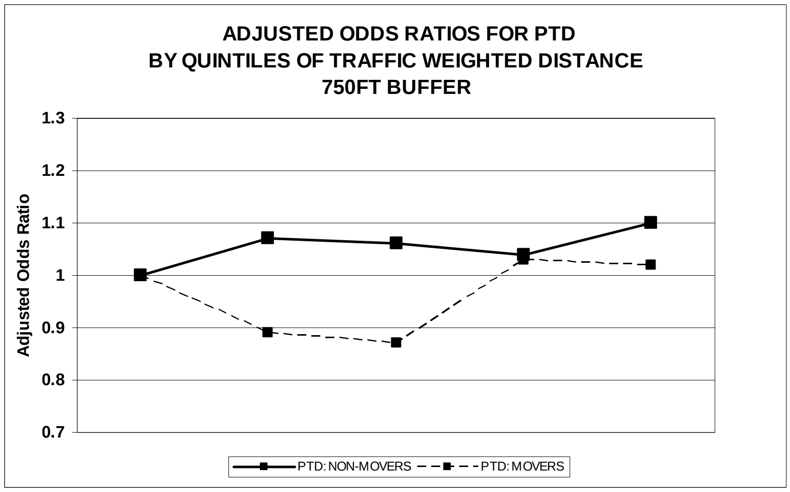
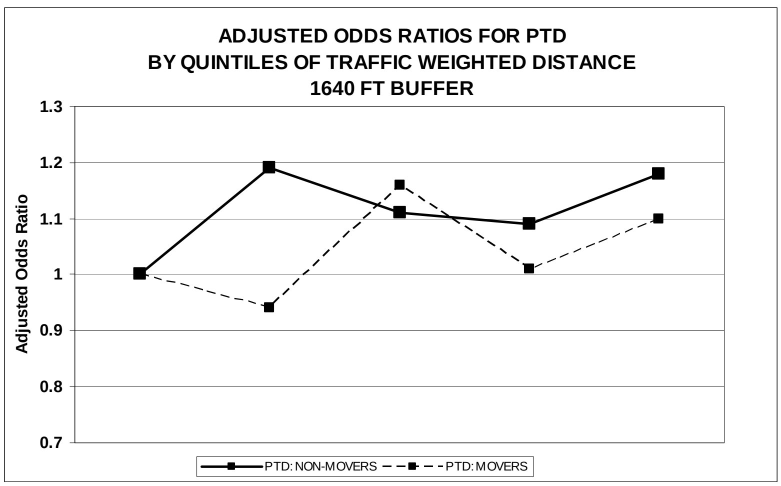


FIGURE 9a-9c: COMPARISON OF MOVERS AND NON-MOVERS IN THREE NESTED DISTANCE FROM ROADWAY BUFFERS ADJUSTED ODDS RATIOS FOR PTD VS. COMPARISON-GROUP BY QUINTILE OF TRAFFIC WEIGHTED DISTANCE





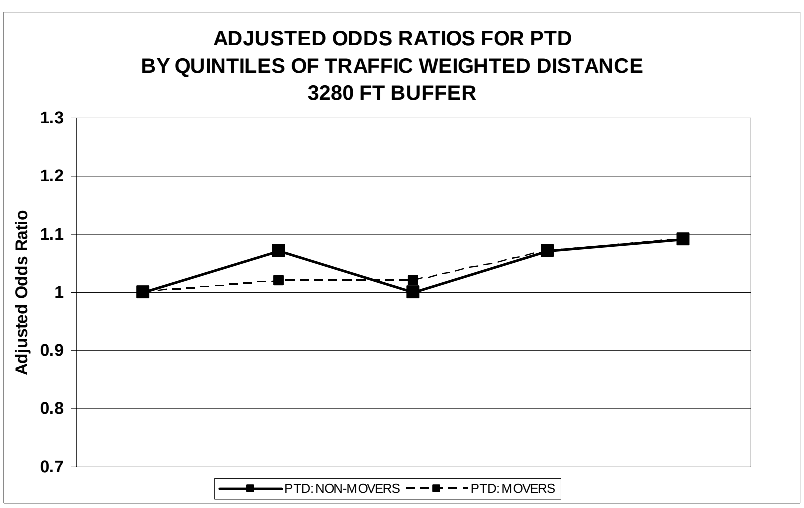
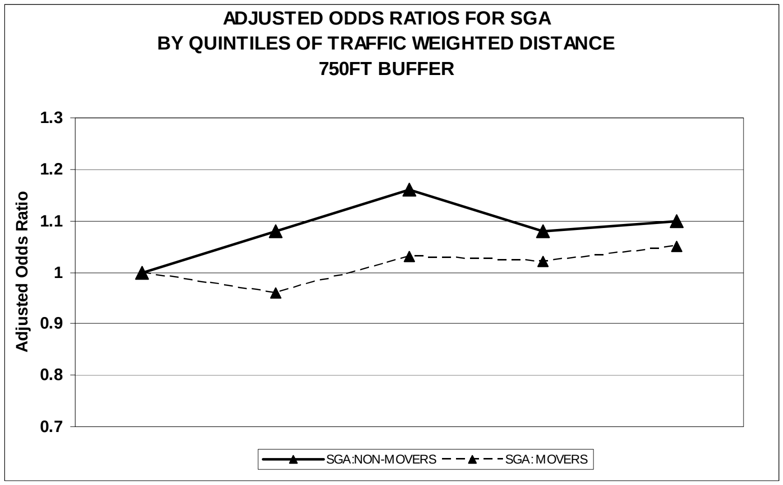
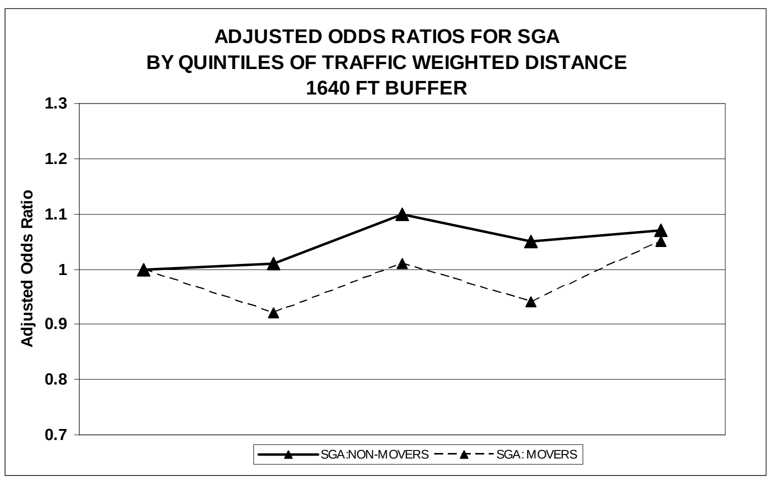
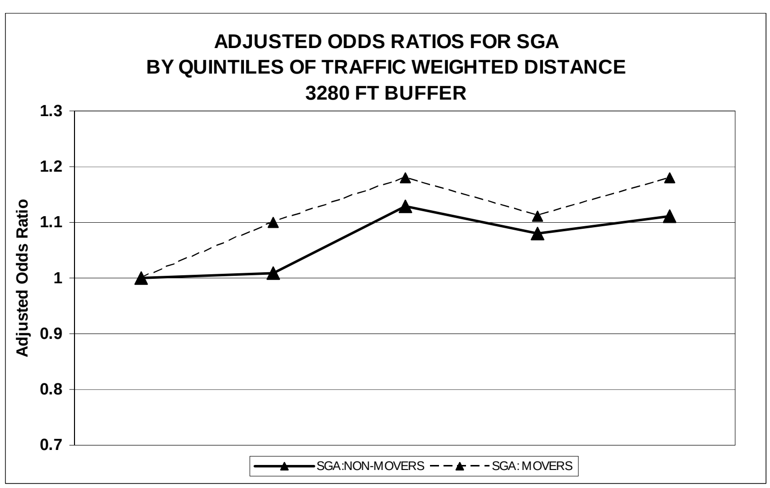


FIGURE9a-9C: COMPARISON OF MOVERS AND NON-MOVERS IN THREE NESTED DISTANCE FROM ROADWAY BUFFERS ADJUSTED ODDS RATIOS FOR SGA VS. COMPARISON-GROUP BY QUINTILE OF TRAFFIC WEIGHTED DISTANCE







CONCLUSION

This purpose of this dissertation was to explore different aspects of mobility during pregnancy and to assess the effect of a change in residency during pregnancy on the possible association between traffic proximity and density, as a proxy for air pollution, and adverse reproductive outcomes of LBW, PTD and SGA. We were motivated by the public health challenge of increasing rates of these outcomes nationwide, the hypothesis that air pollution may be causally related to these outcomes, and the absence of research assessing the role that a change in residency may have on these outcomes, whether that be as a confounder, effect modifier and/or indicator of exposure misclassification.

Based on our results, we conclude that a change in residence during pregnancy does matter – that it should be considered in epidemiological studies of adverse reproductive outcomes. This conclusion is based on the findings from each individual study we undertook.

In our first study, we found that a large proportion (32%) of women in Washington State moved during pregnancy and that almost half of these (45%) moved in the third trimester. We found that mothers who moved were demographically different than non-movers in terms of age, education, race, martial status, income, and employment status. Compared to the neighborhoods in which non-movers lived at the time their child was born, the neighborhoods to which movers moved were more urbanized, less residentially stable, and had higher percentages of rental and vacant housing units.

In our second research effort, we found that after adjusting for maternal socio-demographics and pregnancy risk factors, the odds ratios for LBW and SGA for mobile mothers, compared to non-mobile mothers, were elevated overall and across all trimesters and were strongest in the third trimester. For PTD the odds ratio was slightly elevated in the third trimester only. We also found that a move anytime during pregnancy modified the effect of parity on LBW, SGA and PTD. Compared to multiparous non-movers, the odds ratios for multiparous movers for LBW, SGA and PTD, were elevated above unity. However, the odds ratios for LBW, PTD and SGA for primparous movers were lower than the odds ratios for primparous non-movers.

Finally, in our third research effort, we found that the birth residences of LBW, PTD and SGA births, compared to births without these outcomes, and the birth residences of movers, compared to that of non-movers, were located closer to roadways and had higher weighted traffic exposures. When stratified by mobility status, we observed higher adjusted odds ratios for our outcomes of interest for movers, compared to non-movers, when living within 750 ft. of a roadway compared to living more than 750 ft. from a roadway. Conversely, we found higher adjusted odds ratios for non-movers for the quintiles of weighted traffic exposure when data were limited to those within 750 ft. of a major roadway and 1640 ft. of a major roadway.

Our models examining the direct effect of mobility on our outcomes of interest supplement our knowledge of the possible association between sociological/demographic factors and our outcomes of interest and helps focus the question more closely for future studies. It is unclear from our traffic models whether the different effects we observed for movers vs. non-movers are due to factors we did not sufficiently capture in our analyses, such as differences in health status, access to care, neighborhood SES and emotional stress, or whether the different effects were due to differences in traffic exposure i.e. whether there was exposure misclassification based on birth residence. Overall, our results strongly suggest that mobility during pregnancy remains a factor to be considered in similar analyses

As with any research endeavor, ours suggests numerous avenues for future exploration. These include, but are not limited to, studies on the accuracy of reported residency time and reasons why mothers change residency during pregnancy. In addition, utilizing more recently developed analytic techniques for assessing air pollution exposure, such as a Land Use Regression Model, is also recommended.

We are grateful for the unique opportunity we had to do this research. Washington State has been collecting residency time on its birth certificate since 1989 and has been very gracious and willing for us to use their data. To our knowledge, ours was the first study to utilize the time-at-current-residency data field. Our research returns to Washington State the confirmation that its data collection efforts have be valuable, that the data which were easy to obtain and required no additional costs had a high response rate and provided precise information on who changes residency during pregnancy. Our research also suggests that public health practice could be improved by targeting multiparous mothers who are more likely to have our outcomes of interest if they moved during pregnancy. We would also suggest the expansion of this data field to include time and location of at least one previous residence in order to provide answers to several of the questions that have arisen, such as distance between current and prior residence and exposures at previous residences. Our research certainly makes a valuable contribution by providing a preliminary look at the potential importance of a change in residency during pregnancy and its effect on adverse reproductive outcomes.

CURRICULUM VITAE
SYLVIA R. BROWN, MPH

EDUCATION
Current

UNIVERSITY OF MEDICINE & DENTISTRY OF NEW JERSEY (UMDNJ), SCHOOL OF PUBLIC HEALTH / RUTGERS UNIVERSITY Piscataway, NJ 09/2003 – 05/2009
DEGREE: PhD, Public Health
SPECIALIZATION: Epidemiology

Earned Degrees

UNIVERSITY OF MEDICINE & DENTISTRY OF NEW JERSEY (UMDNJ) / RUTGERS UNIVERSITY Piscataway, NJ 01/1993 -05/1996
DEGREE: Master of Public Health, May 1996
SPECIALIZATION: Epidemiology and Quantitative Methods

UNIVERSITY OF PENNSYLVANIA Philadelphia, PA. 09/1965 -05/1969
DEGREE Bachelor of Arts, Cum Laude, May 1969
SPECIALIZATION History

EMPLOYMENT
Appointed Personnel/Researcher University of Arizona, Tucson, AZ 07/1998--*present*
Research Analyst UMDNJ/Rutgers University, Piscataway, NJ 05/1994-12/2000
Software Developer, RICOMM Systems, Marlton, NJ, 11/1991-03 1993
Senior Analyst, Continental Insurance Co, Cranbury NJ. 02/1990-11/1991
Computer Programmer/ Analyst, INFOMED,Princeton, NJ 02/1985-02/1990

PEER-REVIEWED PUBLICATIONS

1. Begay RC, Goodluck C, Coe K, **Brown S**, Martin L. *Hopi traditionalism and breast and cervical cancer screening*. J Native Aging Health 2, 2007.

2. D. Wartenberg, D Schneider, **S. Brown**, *Childhood leukaemia incidence and the population mixing hypothesis in US SEER data,* British Journal of Cancer (2004), 90, 1771-1776, (04 May 2004).

3. Hakim IA , Robin B. Harris, H-H Sherry Chow, Michael Dean, **Sylvia Brown**, and Iqbal Unnisa Ali *Effect of a 4-Month Tea Intervention on Oxidative DNA Damage Among Heavy Smokers: Role of GST Genotypes* Cancer Epidemiology, Biomarkers & Prevention, Feb. 2004, 2004; 13: 242-249.

4. Hakim IA, Robin B. Harris, **Sylvia Brown**, H-H Sherry Chow. Sheila Wiseman, Sanjiv Agarwal, and Wendy Talbot, *Effect of Increased Tea Consumption on Oxidative DNA Damage Among Smokers: A Randomized Controlled Study.* J of Nutrition. 133:3303S-3309S; 2003.

5. Wartenberg D, **Brown S**, Mohr S, Cragle DL, Friedlander B. (2001) *Are African American Nuclear Workers at Lower Mortality Risk than Caucasians,* Journal of Occupational and Environmental Medicine. 43(10): 861-871.

6. Williams B, Suen H, **Brown S**, Bruhn R, de Blaquiere R, and Rzasa S. (2001) *A Hierarchical Linear Model of Factors Associated with Public Participation among Residents living near the U.S. Army's Chemical Weapons Stockpile Sites.* Environmental Planning and Management. 44(1): 41-65.