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Redefining the Child Pedestrian Safety Paradigm

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Nick Ferenchak, PhD
PhD Student
University of Colorado Denver
Department of Civil Engineering

Current: Assistant Professor
University of New Mexico
Department of Civil, Construction & Environmental Engineering
1 University of New Mexico, Albuquerque, NM 87131
ferenchak@unm.edu

Wesley E. Marshall, PhD, PE
Associate Professor
University of Colorado Denver
Department of Civil Engineering
1200 Larimer Street Denver, CO 80217
wesley.marshall@ucdenver.edu

Bruce Janson, PhD
Professor
University of Colorado Denver
Department of Civil Engineering
1200 Larimer Street Denver, CO 80217
bruce.janson@ucdenver.edu

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Disclaimer

ABSTRACT

Child pedestrians are some of the most vulnerable users of our transportation systems, and they deserve particular attention when we consider traffic safety. Part 1 of this report identifies locations in urban areas where child pedestrians are at particular risk for fatal collisions with vehicles. We do so by examining 30 years of crash data for six American cities in order to locate areas with high child pedestrian fatality concentrations. Phase I of the study, which examined Denver, CO, revealed higher concentrations of child pedestrian fatalities around parks, as compared with other areas that children have been shown to frequent. In Phase II of the study, we specifically examined fatality concentrations near parks as compared with schools. Statistical analyses suggest that, once exposure is controlled for, child pedestrian fatalities concentrate around parks in densities 1.04 to 2.23 times higher than around schools. Also, the concentration of child pedestrian fatalities around parks is 1.16 to 1.81 times higher than the respective citywide concentration. Traffic risks for children around parks deserve further examination as we pursue the goals of Vision Zero and child safety on our streets.

Traditional pedestrian and bicycle safety analyses take a reactive approach to traffic safety by investigating crashes, injuries, or fatalities after they occur. Also, examining trips that have been suppressed because of perceived road safety concerns facilitates a more proactive safety approach; however, a methodology must first be developed to estimate the number of pedestrian and bicycle trips that are suppressed specifically due to road safety concerns. Part 2 of this report accomplishes this by examining child pedestrian and bicycle trips to and from schools in Denver. By combining suppression rates derived from a survey examining parental perceptions of safety and the upper limit of trip frequencies derived from a GIS network analysis, we explore how grade level, gender, and adult supervision are related to childhood travel allowance in terms of street-level design characteristics, such as posted speed limits, vehicle volumes, presence of sidewalks and bike lanes, and the number of vehicle lanes. We then investigate how widespread these suppressed trips are by quantifying the number of children that are impacted and how their routes are altered. We finally detect built environment characteristics – such as street-level designs, network configurations, barriers, and destination siting – linked with high levels of suppressed trips. By integrating this tool with traditional traffic safety analyses, we hope to not only make the places where children are currently walking and biking safer, but to improve safety in places where children should walk and bike.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PART 1: REDEFINING THE CHILD PEDESTRIAN SAFETY PARADIGM: IDENTIFYING HIGH FATALITY CONCENTRATIONS IN URBAN AREAS[1]

1. INTRODUCTION

Walking for transportation during childhood has important health and social benefits as it encourages physical activity and independence (Larsen, Buliung, & Faulkner, 2013; Loukaitou-Sideris & Sideris, 2010). Yet, children are often not able or allowed to safely and comfortably walk to their destinations. Traffic safety is one of the primary barriers to such active transportation in children (Dellinger, Staunton, & CDC, 2002). Motor vehicle collisions are the leading cause of death for individuals from ages 4 through 24 in the United States, with pedestrians being the second most at-risk user type (Centers for Disease Control and Prevention, 2014). Every hour, an average of 40 children die on roadways around the world, most of whom are vulnerable road users such as pedestrians (Toroyan & Peden, 2007). Despite the unfortunate road safety statistics of child pedestrians and the known health benefits of childhood walking, our transportation networks remain alarmingly dangerous for the few children that still walk independently. The question addressed through this work is: are there other land uses where we should be focusing our resources – beyond our traditional focus on schools – to alleviate large concentrations of child pedestrian fatalities?

Many researchers and practitioners have exerted considerable effort exploring child pedestrian safety around schools. These researchers and practitioners have found success when the necessary resources are allotted to combat the problem near school grounds. For example, reduced speed limits in school zones have been shown to lower vehicle speeds, while projects funded by the Safe Routes to School program have reduced child pedestrian injury rates (Abdul-Hanan, King, MJ, & Lewis, 2011; DiMaggio & Li, 2013; Dumbaugh & Frank, 2007; Graham & Sparkes, 2010; Orenstein, Gutierrez, N., & Rice, 2007). However, other locations within our cities frequented by children remain relatively unexplored (Kattan, Tay, & Acharjee, 2011; Tay, 2009). The scant literature on the subject suggests that the areas around trails have relatively few child pedestrian crashes, while other research found that areas with few child pedestrian injuries contained a prevalence of parks and play areas, and similarly, that areas at high risk for traffic crashes involving pedestrians under the age of 15 were characterized by an absence of parks (Joly, Foggin, & Pless, 1991; Kraus, Hooten, & Brown, 1996; Stutts & Hunter, 1999). Furthermore, an analysis of child injuries associated with playground visits in the United States found that pedestrian injuries were so uncommon that a statistical analysis was not possible (Phelan, Khoury, Kalkwarf, & Lanphear, 2001). This current work will fill the gap in the literature by further exploring concentrations of child pedestrian fatalities throughout our urban areas.

In Phase I of the study, we use spatial and statistical analyses to compare child pedestrian fatality concentrations around schools to concentrations around other areas in Denver that children may frequent, such as recreation centers, parks, and trails, using 31 years of crash data (Lee, Booth, & Reese-Smith, 2005; Loukaitou-Sideris, 2003). In Phase II, based on findings from the first analysis, we examine parks relative to schools in six different cities. The goal is to identify high concentrations of child pedestrian fatalities so we can best protect children in our cities.

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2. DATA

The study cities were selected because focusing on rapidly growing cities would allow for the examination of current development patterns. While early U.S. cities were designed with pedestrians and streetcars in mind, those developed over the last century were primarily designed to cater to the automobile. Studying these modern auto-centric cities will allow the results to inform current building practices. By having a clearer understanding of the implications of our current community designs, we can build safer places for even the most vulnerable road users. According to census data, the south was the quickest growing region between 2000 and 2013, while the west was close behind (D.T. Cohen, Hatchard, & Wilson, 2015). Therefore, cities from these two regions became the focus of this study.

Of the 25 most populous places across the United States, Austin had the largest percentage increase in population from 2000 to 2013, Charlotte had the second largest increase, Denver had the third largest increase, and Dallas had the tenth largest increase (D.T. Cohen et al., 2015). Houston had the second largest growth in total population, while Los Angeles had the fourth largest total growth (D.T. Cohen et al., 2015). These cities with substantial population growth are important to study because they are installing new infrastructure in new and unique land use configurations. The safety outcomes of these new land use configurations are what we hope to explore through this work. Other cities with high growth rates were not used because comprehensive school, park, trail, and crash data were not available due to a lack of data collection.

2.1 Crash Data

We acquired child pedestrian fatality locations from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS) for 1982 through 2012. These data were available from 1982 to 2000 in address format, and from 2001 until 2012 with latitude and longitude coordinates. Crashes from 1982 to 2000 were geocoded on either the address-level or, if the data did not contain enough detail, the street-level. Children were defined as persons under age 18. City boundaries were defined by the "Places" shapefile provided by the U.S. Census Bureau through its Topologically Integrated Geographic Encoding and Referencing (TIGER) products.

2.2 Exposure Data

Due to consistency issues, finding reliable child pedestrian exposure data in geographically broad studies has historically been difficult (Wier, Weintraub, Humphreys, Seto, & Bhatia, 2009). The best option for this particular study, when numerous exposure approaches were assessed, was to use a population-based exposure metric, such as that used by DiMaggio and Li (2013) in their safety examination of the Safe Routes to School program (DiMaggio & Li, 2013). In their study, DiMaggio and Li (2013) used the number of pedestrian crashes in selected census tracts and the number of persons living in those same census tracts to create a rate of crashes per 10,000 population for each of the tracts (DiMaggio & Li, 2013). While past studies modeled pedestrian exposure using proxy factors, such as road network characteristics, land use, and socio-economics, population-based exposure metrics are also common and have proven useful for preliminary and/or geographically broad work (Jacobsen, 2003; Wier et al., 2009). Given that our study fits both of these conditions, a population-based metric facilitated a consistent child pedestrian exposure metric to study road safety across six U.S. cities. Although there were a number of limitations associated with this population-based exposure metric (which will be detailed in the Conclusion section), analysis on the block group level did allow for finer-grained contexts to be considered.

The exposure variable for the analysis was the number of children living within the analysis zones. This variable was created by pulling the child populations for each block group from the 2010 census and creating a random point for each child resident. This served as an indicator of the total number of children and a proxy for the relative level of child pedestrian traffic exposure in the study areas. This population-based exposure approach allows for a conservative analysis in terms of parks because exposure around schools is typically higher than around parks. Almost all children attend school while not all children use parks. Also, schools get usage from weekday school trips and recreational trips for playgrounds and sports fields on the grounds, while parks only experience usage for recreational purposes. Using the same population-based exposure approach for all areas ensured a thoroughly conservative analysis of the risk around parks.

2.3 Child-Friendly Destinations Data

We chose child-friendly destinations because past research identified them as public places that children frequent as both recreational and physical activity resources (Lee et al., 2005; Loukaitou-Sideris, 2003). We obtained locational data for the child-friendly destinations from the publicly available 2015 open data catalogs for the respective cities. The number of schools and parks within the study cities ranged widely (Table 2.1). Buffers were then created based on the location of the buildings for schools and recreation centers and based on the parcel boundary for parks. This facilitated a more accurate representation of access than, for instance, if parks were based on a single point. The buffers for the trails were drawn adjacent to the entire trail; however, this may not be representative of the actual access points. Study areas were designated by quarter-mile buffers around the facilities. This quarter-mile buffer size was chosen because it has been shown to be an appropriate access threshold for children, or the longest distance that children are typically allowed or able to independently walk to their destinations (Wolch, Wilson, & Fehrenbach, 2005). Also, the shortest service area with which parks and recreation areas are typically designed is one-quarter mile (D.A. Cohen et al., 2006). For instance, regional parks are normally designed to serve entire cities, while pocket parks may be designed to serve just the surrounding blocks. Because every park has at least a quarter-mile service area, this is an effective buffer size to use.

An 'Erase' command was run on the park buffers so that the actual parks were not included in the buffer area. Since there were no fatalities within the parks, erasing the park area did not impact the number of fatalities, but ensured that the exposure variable was not inflated. Thus, the park buffer consisted of only the land one-quarter mile outside of each park.

Table 2.1 Descriptive Statistics for Study Cities

	Population	Schools	Park Area (Hectare)	Rec. Centers (count)	Trails (km)
Austin	931,840	226	6,742.6	-	-
Charlotte	827,121	263	8,016.2	-	-
Dallas	1,300,082	221	7,618.6	-	-
Denver	682,545	227	7,583.2	30	142
Houston	2,298,628	1,180	10,236.5	-	-
Los Angeles	3,971,896	3,689	25,868.4	-	-

3. METHODS

In Phase I, we examined child pedestrian fatality concentrations at four destinations that children frequent (i.e., schools, recreation centers, trails, and parks) in Denver. The other study cities were omitted in Phase I because of limited data. In Phase II, we investigated schools and parks in more detail across six study cities.

3.1 Phase I Study Methodology

Upon completion of data collection and formatting, we initiated spatial analysis by defining the study area buffers and calculating the number of child pedestrian fatalities in those study areas. This was completed through spatial joins in ESRI's ArcMap (Figure 3.1).

After the number of child pedestrian fatalities was derived through spatial queries for each of the zones, the same procedure was run again to find the total number of children living within those zones. This formed the study's exposure variable, allowing for a rate of fatalities per 10,000 children to be operationalized.

There were no child pedestrian fatalities around recreation centers in Denver (Table 3.1). This suggests that recreation centers are not a primary problem for child pedestrian safety. Trails had rates similar to schools and parks. However, it is not clear if children use trails in the same manner they use parks and schools. Access to trails is typically constrained, and the location of the child pedestrian fatalities near trails did not appear to necessarily correlate with trail access points. Trails typically have limited access points, while child-friendly destinations such as parks have more permeable access along their borders (Cutts, Darby, Boone, & Brewis, 2009; Krizek, Barnes, & Thompson, 2009; Krizek, El-Geneidy, & Thompson, 2007; Price, Reed, & Muthukrishnan, 2012). Parks were of interest because they had the highest fatality rates. We therefore examined parks in Phase II by comparing their fatality rates to the fatality rates around schools, which have been the traditional focus.

Table 3.1 Child Pedestrian Fatality Rates per 10,000 Children near Child-Friendly Locations

	Schools	Rec Centers	Trails	Parks
Fatalities near child-friendly locations	**3.51** per 10,000 children	**0.00** per 10,000 children	**3.58** per 10,000 children	**3.64** per 10,000 children

3.2 Phase II Study Methodology

Based on findings from the preliminary study, a second analysis of child pedestrian safety around parks was warranted. Parks and schools were therefore examined in more detail for six cities: Austin, TX; Charlotte, NC; Dallas, TX; Denver, CO; Houston, TX; and Los Angeles, CA.

Using the same procedure from the previous analysis, the child populations and the number of child pedestrian fatalities were derived for analysis (Table 3.2). These variables were considered for areas near schools, near parks, near schools or parks, and near neither schools nor parks. The level of risk was derived for each city, location type, and year within the study. Confidence intervals were then computed.

Table 3.2 Child Pedestrian Fatality Statistics & Child Resident Statistics near Destinations

	Child Pedestrian Fatalities			**Child Population (thousands)**		
	Total	Schools (%)	Parks (%)	Total	Schools (%)	Parks (%)
Austin	32	5 (15.6%)	15 (46.9%)	173	33 (18.9%)	70 (40.4%)
Charlotte	62	12 (19.4%)	42 (67.7%)	177	23 (12.7%)	66 (37.4%)
Dallas	108	13 (12.0%)	62 (57.4%)	325	57 (17.6%)	122 (37.6%)
Denver	37	17 (45.9%)	29 (78.4%)	129	48 (37.6%)	80 (61.8%)
Houston	172	39 (22.7%)	45 (26.2%)	564	128 (22.8%)	121 (21.5%)
Los Angeles	417	246 (59.0%)	167 (40.0%)	872	486 (55.8%)	208 (23.9%)

Figure 3.1 Child Pedestrian Fatalities Relative to Park Buffers in Denver

4. RESULTS

The results suggest that, for all of the study cities, child pedestrian fatality rates are significantly higher in areas near a school or a park than in areas near neither a school nor a park (Table 4.1). Fatality rates in areas near a park or a school are significantly higher than the average citywide rates for five of the six study cities and not significantly different for one of the study cities.

Table 4.1 Child Pedestrian Fatality Rates per 10,000 Children Living Around Schools or Parks or Neither Schools nor Parks with 95% Confidence Intervals

	Citywide	Schools or Parks	Neither Schools nor Parks	% Difference*
Austin	1.85 (1.71, 1.99)	2.14 (1.91, 2.37)	1.57 (1.40, 1.74)	36.3%
Charlotte	3.51 (3.28, 3.74)	5.77 (5.36, 6.18)	1.72 (1.56, 1.88)	**235.5%**
Dallas	3.32 (3.17, 3.47)	4.36 (4.10, 4.62)	2.39 (2.22, 2.56)	**82.4%**
Denver	2.87 (2.73, 3.01)	3.34 (3.15, 3.53)	1.52 (1.30, 1.74)	**119.7%**
Houston	3.05 (2.95, 3.15)	3.60 (3.43, 3.77)	2.69 (2.57, 2.81)	**33.8%**
Los Angeles	4.78 (4.58, 4.98)	5.34 (5.11, 5.57)	3.73 (3.53, 3.93)	**43.2%**

**Statistically Significant Percent Differences from Schools or Parks to Neither Schools nor Parks are Bold*

Risk was found to be higher around parks than around schools for all study cities (Table 4.2). Dallas has the largest difference between schools and parks in terms of risk, with child pedestrians being more than twice as likely to experience a fatality within close proximity to a park than within close proximity to a school. All of the fatality rates around parks are significantly higher than the rates around schools, except for those in Denver. Rates around parks are also higher than the average rates citywide for all study cities, and are significantly higher for each city, except for Austin. Rates around schools are higher than the average citywide rates for just three of the six study cities, and only two of these are significantly higher.

Table 4.2 Child Pedestrian Fatality Rates per 10,000 Children Living Around Schools and Parks with 95% Confidence Intervals

	Schools	Parks	% Difference*
Austin	1.53 (1.31, 1.75)	2.14 (1.90, 2.38)	**40.5%**
Charlotte	5.33 (4.79, 5.87)	6.35 (5.87, 6.83)	19.1%
Dallas	2.27 (2.02, 2.52)	5.07 (4.74, 5.40)	**123.3%**
Denver	3.51 (3.20, 3.82)	3.64 (3.42, 3.86)	3.7%
Houston	3.04 (2.87, 3.21)	3.71 (3.49, 3.93)	**22.0%**
Los Angeles	5.06 (4.82, 5.30)	8.01 (7.51, 8.51)	**58.3%**

**Statistically Significant Percent Differences from Schools to Parks are Bold*

5. CONCLUSIONS

While past efforts to ensure child pedestrian safety have focused primarily on schools, findings from this work suggest that parks may be an important location to focus on as well. Among all six study cities, risk for child pedestrian fatalities is higher around parks than around schools, although not all of these differences were statistically significant. The risk around parks has, prior to this research, been largely overlooked. Reasons for higher rates around parks may include unsafe streets, along with a general lack of awareness, focus, education, and engagement in terms of the transportation safety issues present.

There are two perspectives through which we may interpret solutions to this problem: transportation and urban design. Taking a transportation approach to the problem would have us lowering vehicle speeds and making drivers aware of child pedestrians through street design changes, such as traffic calming, road diets, or pedestrian crossing treatments. A broader urban design approach would focus on the siting of our parks. If we site a park next to a six-lane roadway with a high design speed, few transportation treatments would be able to help. Within the study cities, it was not uncommon to have a park separated from the community it serves by roadways with four or six lanes. Some of these roadways have been documented with vehicle speeds greater than 70 mph next to the adjacent park (Marshall, 2015). Siting parks on slow and narrow local roads within neighborhoods may help alleviate safety issues and thereby induce higher levels of independent walking. The most effective solution to the problem may very well lie in a combination of both these approaches. We will need to ensure that parks are sited safely within neighborhoods, and pedestrian infrastructure is included in a cohesive network to ensure safe access. In addition to these built environment improvements, other approaches – such as child education, driver education, and enforcement methods – may prove effective.

There were several limitations present in this study. Many of the limitations were related to the measurement of child pedestrian exposure. It was necessary to have a consistent exposure metric, which led to a population-based exposure metric. We considered conducting a survey in order to measure exposure, but survey data have been found to significantly underrepresent child pedestrian exposure, and low response rates may introduce self-selection issues (Roberts, Keall, & Frith, 1994; Routledge, Repetto-Wright, & Howarth, 1974). We also considered observational data, but they fail to properly consider potential endogeneity issues between perceived risk and exposure; in other words, a road perceived to be dangerous could be the cause of the low exposure and result in a seemingly good safety record. This would violate the independence assumption of most statistical models (Cho, Rodriguez, & Khattak, 2009). Moreover, observational data are difficult to acquire across multiple cities in large enough numbers to ensure sample sizes that reach statistical significance and are representative of actual conditions (Stevenson, 1991). For these reasons, a population-based exposure metric was utilized. The exposure metric assumes that individual children will be exposed to traffic dangers at similar rates across the study cities. While this assumption is not necessarily ideal, most children walking to a child-friendly destination, such as a school or park, would likely live within a quarter-mile of that school or park (Wolch et al., 2005). Examining finer geographic levels and exploring different methods of operationalizing child pedestrian exposure will be necessary in order to obtain a better understanding of the issue.

The fact that children of all ages are assumed to act similarly and experience similar risk is another limitation of the exposure metric. In other words, the risk to a 5-year-old pedestrian walking independently to a park is most likely higher than the risk to a 13-year-old walking independently to a park. However, the 5-year-old pedestrian is more likely to be accompanied by a parent, which typically alleviates some of the risk. This relationship between age and risk is complex and deserves more attention. Also, examining risk for child pedestrian injuries around parks would provide larger sample sizes and more robust statistical analysis than child pedestrian fatalities. Focusing on finer geographic levels may allow for an injury-specific analysis.

A further limitation was the lack of knowledge pertaining to installation dates of schools and parks. It should also be noted that results may be exclusive to the generally warm climates of the study cities, and generalizability of the findings should not be assumed for other contexts. Other factors that may prove to be important include social factors, such as population density, poverty, and crime, and built environment factors, such as travel lanes, vehicle speeds, and cartway width.

Child pedestrians, being highly vulnerable users of our transportation systems, find themselves at substantial risk as they move about our cities. Ensuring their safety is of the utmost importance. However, in order to ensure that safety, one must understand where safety risks are located. This study has shown that, opposed to traditional beliefs, there are higher concentrations of child pedestrian fatalities around parks than around schools. A shift in the child traffic safety paradigm is now needed to focus treatment efforts around our parks.

6. REFERENCES

Abdul-Hanan, S., King, M.J., & Lewis, I. (2011). "Understanding speeding in school zones in Malaysia and Australia using an extended theory of planned behaviour:the potential role of mindfulness." In (Vol. 22, pp. 56-62): *J Australas Coll Road Saf*.

Centers for Disease Control and Prevention. (2014). Ten Leading Causes of Death and Injury. In: Injury Prevention & Control: Data & Statistics.

Cho, G., Rodriguez, D., & Khattak, A. (2009). "The role of the built environment in explaining relationships between perceived and actual pedestrian and bicyclist safety." *Accident Analysis and Prevention, 41*(4), 692-702. doi:10.1016/j.aap.2009.03.008

Cohen, D., Ashwood, J., Scott, M., Overton, A., Evenson, K., Staten, L., . . . Catellier, D. (2006). "Public parks and physical activity among adolescent girls." *Pediatrics, 118*(5), E1381-E1389. doi:10.1542/peds.2006-1226

Cohen, D., Hatchard, G., & Wilson, S. (2015). Population Trends in Incorporated Places: 2000 to 2013. In: U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau.

Cutts, B., Darby, K., Boone, C., & Brewis, A. (2009). "City structure, obesity, and environmental justice: An integrated analysis of physical and social barriers to walkable streets and park access." *Social Science & Medicine, 69*(9), 1314-1322. doi:10.1016/j.socscimed.2009.08.020

Dellinger, A., Staunton, C., & CDC. (2002). "Barriers to children walking and biking to school - United States, 1999" (Reprinted from MMWR, vol 51, pg 701-704, 2002). *Jama-Journal of the American Medical Association, 288*(11), 1343-1344.

DiMaggio, C., & Li, G. (2013). "Effectiveness of a Safe Routes to School Program in Preventing School-Aged Pedestrian Injury." *Pediatrics, 131*(2), 290-296. doi:10.1542/peds.2012-2182

Dumbaugh, E., & Frank, L. (2007). "Traffic safety and Safe Routes to Schools - Synthesizing the empirical evidence." *Transportation Research Record*(2009), 89-97. doi:10.3141/2009-12

Graham, A., & Sparkes, P. (2010). "Casualty Reductions in NSW Associated with the 40 km/h School Zone Initiative." In: *2010 Australasian Road Safety, Research, Policing and Education Conference*.

Jacobsen, P. (2003). "Safety in numbers: more walkers and bicyclists, safer walking and bicycling." *Injury Prevention, 9*(3), 205-209. doi:10.1136/ip.9.3.205

Joly, M., Foggin, P., & Pless, I. (1991). "Socioecological determinants of the risk of accidents in young pedestrians." In (Vol. 39, pp. 345-351): *Rev Epidemiol Sante Publique*.

Kattan, L., Tay, R., & Acharjee, S. (2011). "Managing speed at school and playground zones." *Accident Analysis and Prevention, 43*(5), 1887-1891. doi:10.1016/j.aap.2011.04.009

Kraus, J., Hooten, E., & Brown, K. (1996). "Child pedestrian and bicyclist injuries: results of community surveillance and a case-control study." In (Vol. 2, pp. 212-218): *Inj Prev*.

Krizek, K., Barnes, G., & Thompson, K. (2009). "Analyzing the Effect of Bicycle Facilities on Commute Mode Share over Time." *Journal of Urban Planning and Development-Asce, 135*(2), 66-73. doi:10.1061/(ASCE)0733-9488(2009)135:2(66)

Krizek, K., El-Geneidy, A., & Thompson, K. (2007). "A detailed analysis of how an urban trail system affects cyclists' travel." *Transportation, 34*(5), 611-624. doi:10.1007/s11116-007-9130-z

Larsen, K., Buliung, R., & Faulkner, G. (2013). "Safety and School Travel: How Does the Environment Along the Route Relate to Safety and Mode Choice?" *Transportation Research Record*(2327), 9-18. doi:10.3141/2327-02

Lee, R., Booth, K., & Reese-Smith, J. (2005). "The physical activity resource assessment (PARA) instrument: evaluating features, amenities and incivilities of physical activity resources in urban neighborhoods." In (Vol. 2, pp. 13): *Int J Behav Nutr Phys Act*.

Loukaitou-Sideris, A. (2003). "Children's common grounds - A study of intergroup relations among children in public settings." *Journal of the American Planning Association, 69*(2), 130-143. doi:10.1080/01944360308976302

Loukaitou-Sideris, A., & Sideris, A. (2010). "What Brings Children to the Park? Analysis and Measurement of the Variables Affecting Children's Use of Parks." *Journal of the American Planning Association, 76*(1), 89-107. doi:10.1080/01944360903418338

Marshall, W. E. (2015). "Understanding the impacts of integrating New Urbanist neighborhood and street design ideals with conventional traffic engineering standards: the case of Stapleton." In (Vol. 8, pp. 148-172): *J Urban*.

Orenstein, M., Gutierrez, N, & Rice, T. (2007). "Safe Routes to School Safety and Mobility Analysis." In: Safe Transportation Research & Education Center.

Phelan, K., Khoury, J., Kalkwarf, H., & Lanphear, B. (2001). "Trends and patterns of playground injuries in United States children and adolescents." *Ambulatory Pediatrics, 1*(4), 227-233. doi:10.1367/1539-4409(2001)001<0227:TAPOPI>2.0.CO;2

Price, A., Reed, J., & Muthukrishnan, S. (2012). "Trail User Demographics, Physical Activity Behaviors, and Perceptions of a Newly Constructed Greenway Trail." *Journal of Community Health, 37*(5), 949-956. doi:10.1007/s10900-011-9530-z

Roberts, I., Keall, M., & Frith, W. (1994). "Pedestrian Exposure and the Risk of Child Pedestrian Injury." *Journal of Paediatrics and Child Health, 30*(3), 220-223. doi:10.1111/j.1440-1754.1994.tb00622.x

Routledge, D., Repetto-Wright, R., & Howarth, C. (1974). "A comparison of interviews and observation to obtain measures of children’s exposure to risk as pedestrians." In (Vol. 17, pp. 623-638): *Ergonomics*.

Stevenson, M. (1991). "Analytical Approach to the Investigation of Childhood Pedestrian Injuries - A Review of the Literature." *Journal of Safety Research, 22*(3), 123-132. doi:10.1016/0022-4375(91)90002-D

Stutts, J., & Hunter, W. (1999). "Motor vehicle and roadway factors in pedestrian and bicyclist injuries: an examination based on emergency department data." *Accident Analysis and Prevention, 31*(5), 505-514. doi:10.1016/S0001-4575(99)00007-X

Tay, R. (2009). "Speed Compliance in School and Playground Zones." *Ite Journal-Institute of Transportation Engineers, 79*(3), 36-38.

Toroyan, T., & Peden, M. (2007). "Youth and Road Safety." In Geneva, Switzerland: WHO.

Wier, M., Weintraub, J., Humphreys, E., Seto, E., & Bhatia, R. (2009). "An area-level model of vehicle-pedestrian injury collisions with implications for land use and transportation planning." *Accident Analysis and Prevention, 41*(1), 137-145. doi:10.1016/j.aap.2008.10.001

Wolch, J., Wilson, J., & Fehrenbach, J. (2005). "Parks and park funding in Los Angeles: An equity-mapping analysis." *Urban Geography, 26*(1), 4-35. doi:10.2747/0272-3638.26.1.4

PART 2: QUANTIFYING SUPPRESSED CHILD PEDESTRIAN AND BICYCLE TRIPS[2]

7. INTRODUCTION

When traffic safety researchers examine children's pedestrian and bicycle trips to and from school, they typically analyze crashes, injuries, or fatalities while accounting for the number of child pedestrians and bicyclists on the street – also known as exposure. However, this approach to traffic safety is a reactive one, only looking at pedestrians and bicyclists that have deemed the traffic environment safe enough to use, and only looking at the streets where those pedestrians and bicyclists are currently walking or biking. Therefore, these approaches neglect both the pedestrians and bicyclists who want to walk or bike, but do not feel safe enough to do so, and the places where such trips are being suppressed.

To create a more proactive traffic safety analysis, we also need to account for the pedestrian and bicycle trips that never occurred in the first place because of road safety concerns. How would we measure such suppressed trips? Which personal and built environment characteristics would be associated with road safety-related trip suppression? How many children would be impacted by trip suppression, and how would their routes be altered? While traditional mode choice models output the expected share of different modes, we create a model that instead predicts the percentage of trips suppressed due to road safety concerns in order to answer these research questions.

To create this safety perception-based mode choice model, we used results from a survey we administered to parents of elementary and middle school students in Denver, CO, along with linear and logistic regressions to explore how grade level, gender, adult supervision, and street-level design characteristics (e.g., posted speed limits, sidewalks, bike lanes, number of lanes, and vehicle volumes) are related to trip suppression rates. We then derived the total number of trips expected under ideal conditions based on a GIS network analysis. Finally, we combined trip suppression rates with the upper limit of trip frequencies to determine the total number of trips being suppressed specifically due to road safety concerns for every roadway in Denver.

[2] [1]This portion of the report has been peer reviewed and is scheduled for publication: Ferenchak, N. and Marshall, W. "Quantifying Suppressed Child Pedestrian and Bicycle Trips." *Travel Behavior and Society*.

8. THEORY

Crashes, injuries, and fatalities – ideally normalized to levels of user exposure – are typically employed to analyze transportation safety of both motorized and non-motorized users (Administration, 2006; Board, 2001; Waldheim, Wemple, & Fish, 2015; Zegeer, Nabors, Gelinne, Lefler, & Bushell, 2010). However, this reactive approach only accounts for individuals using the facility and neglects those individuals who have deemed the roadway too unsafe to use in the first place. Accounting for suppressed trips is especially prescient for pedestrian and bicycle safety analyses, where many possible users could expect to be dissuaded because of road safety concerns (Schneider, Ryznar, & Khattak, 2004). For example, early research found that the presence of sidewalks resulted in pedestrian volumes nearly four times higher than similar roads lacking sidewalks (Qin, Ivan, & TRB, 2001). Similarly, six times more pedestrians walked on two-lane highways as opposed to four-lane highways (Qin et al., 2001). A survey from China investigated bicyclists who had reduced their riding, and found that, while only 11% did so because they had purchased a car, more than one-third reduced their riding because of heightened safety concerns due to increased motorized traffic (York, 2007).

The World Health Organization (WHO) has speculated that barriers to walking and biking might be the greatest traffic-related health impact (Organization, 2000). However, WHO notes that no one has properly quantified that impact (Organization, 2000). An early literature review focused on walking and biking suppression found that, while negative traffic safety perceptions are correlated with decreases in walking and biking, the relationship has not been properly quantified (Jacobsen, Racioppi, & Rutter, 2009).

Few researchers have ventured to estimate the number of pedestrian and bicycle trips that are suppressed because of traffic safety concerns. Schneider et al. (2004) formulated an early approach by developing a survey to identify areas on the campus of the University of North Carolina at Chapel Hill that are perceived as unsafe – in terms of traffic safety – by pedestrians (Schneider et al., 2004). By asking individuals to identify the three locations on campus that felt the least safe for pedestrians, the researchers were able to identify areas with poor road safety perceptions and theoretically high trip suppression. However, these results are not transferable because the perceptions were not associated with specific built environment characteristics (i.e., street design, network connectivity, land use, etc.). Also, this approach did not unitize the results (i.e., we may know which site is ranked as the least safe, but we do not know the number of actual trips that are being suppressed); therefore, it is difficult to compare levels of suppression between different sites.

Bellemans et al. (2009) similarly used a travel diary that asked respondents to record trips they had planned but never executed (Bellemans, van Bladel, Janssens, Wets, & Timmermans, 2009). While Bellemans et al. (2009) did associate the suppressed trips with built environment characteristics, they looked primarily at household and personal schedule factors rather than the specific impact of road safety (Bellemans et al., 2009). Furthermore, this methodology does not capture suppressed trips that never reached the planning stage. Take, for example, roads perceived as so unsafe, no pedestrian or bicyclist ever planned to use the facility. Such trips have been suppressed due to traffic safety concerns and should be included in an overall analysis of suppressed trips.

Cho et al. (2009) related trip suppression rates to built environment factors, but only examined macro-level environmental characteristics (i.e., land uses and road network density) to estimate suppressed pedestrian and bicyclist trips (Cho, Rodriguez, & Khattak, 2009). While these large-scale factors are certainly important, we wish to examine the impact of individual roadway characteristics because, while it is not easy to change established land use or road network configurations, transportation planners and engineers can more feasibly alter street-level design characteristics.

Nevelsteen et al. (2012) related suppressed pedestrian and bicycle school trips to individual roadway characteristics; however, the researchers only examined two factors, speed limits and the presence of non-motorized facilities (Nevelsteen, Steenberghen, Van Rompaey, & Uyttersprot, 2012a). Furthermore, the study took place in the Flemish Region of Belgium, which, with its high levels of active mobility, presents a radically different context than a typical American city.

All of these past studies used suppressed trip estimates to take a more proactive look at road safety. We will build upon this past work by using parental perceptions of roadway characteristics to determine trip suppression and then apply those results in a citywide analysis.

If we were to estimate suppressed trips based on street-level design characteristics, which characteristics would be important to consider? Past mode choice models found that pedestrian and bicycle facilities, crosswalks and crossing treatments, traffic volumes and speeds, traffic calming features, and crossing guards are important roadway characteristics that predict child mode choice to school (Larsen, Buliung, & Faulkner, 2013). While crossing guards are not included in our analysis because their location may change, we did account for other pertinent factors. Traffic calming features were captured through the inclusion of traffic volumes and speeds, while crossings were represented with a proxy of number of lanes. We structured our analysis in a way that we may understand how these factors are related to one another in terms of suppressed trips (i.e., maybe vehicle speed is an important factor, but it becomes less important if sidewalks are present).

9. DATA

Through this work, we endeavor to design a trip-suppression model based on parental perceptions of roadway characteristics. To do so, data regarding both road safety perceptions and trips are necessary. We garnered perceptions through a survey and estimated trips from a closest facility GIS network analysis using child populations (origins) and school locations (destinations).

We utilized the City and County of Denver to build our safety perception-based model. Denver is the heart of Colorado's Front Range region, with a 2015 population of 649,654 residents (118,886 under 15 years of age) spread out over the city's 155 square miles. The dense downtown is surrounded by medium-density neighborhoods laid out in predominantly gridded street networks. According to Denver Public Schools (DPS), there are 92,331 children enrolled in DPS's 207 schools throughout the city.

9.1 Parental Perceptions Data

We targeted a survey at parents of children in grades pre-kindergarten through eighth grade to garner parental perceptions of traffic safety. The survey excluded parents of high schoolers, because high school students have more independence than elementary and middle school students and would also be more likely to drive themselves or carpool with a friend. The survey was offered exclusively online and marketed through newsletters, fliers, and social media by DPS, parent-teacher organizations, the City and County of Denver, and local advocacy groups. The survey was open for one month from October 5, 2017, until November 5, 2017.

Since 36.8% of DPS students identify as Spanish speakers and 55.5% are Hispanic, we provided the survey and promotional materials in both languages. Respondents first answered whether they would like to take the survey in English or Spanish. We next asked parents how many children they would like to complete the survey for. Parents could complete the survey for up to four children simultaneously. Respondents then provided the grade level and gender of each child included in the survey response.

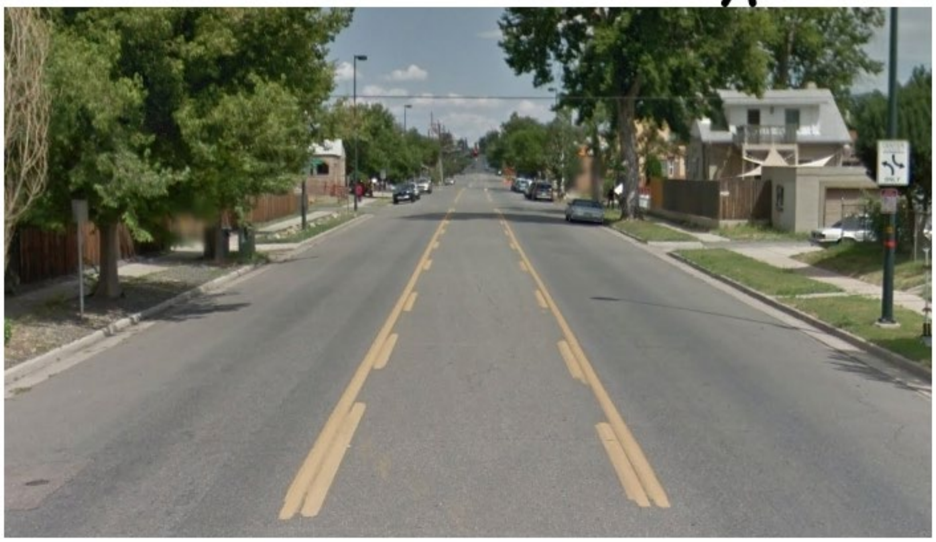
The Leuven Travel Behavior of Children to Primary School Survey (Nevelsteen, Steenberghen, Van Rompaey, & Uyttersprot, 2012b) served as a prototype for the travel behavior questions on the survey. Parents answered whether they would allow their child to either walk or bike along 10 different picture-based roadway scenarios on the child's trip to school (five scenarios for pedestrian questions and five for bicycle questions). While the survey from Nevelsteen et al. (2012) included posted speed limits and presence of active transportation facilities as explanatory factors, Larsen et al. (2013) determined that crossings and vehicle volumes are also important explanatory roadway characteristics (Larsen et al., 2013; Nevelsteen et al., 2012b). Because crossings at intersections can be complex and difficult to represent in a picture (e.g., varying phasing, signalization, markings, signage, turning movements, etc.), we chose to utilize a combination of variables, including the number of lanes, posted speed limits, and vehicle volumes, as a proxy for crossing risk. While not perfect, these variables are related to the amount of time spent exposed to traffic risk and the degree of that risk. Accordingly, each roadway scenario in our survey had four different characteristics identified for the parent: the speed limit of the roadway, the number of lanes, the presence of active transportation facilities (i.e., a sidewalk for walking questions or a bike lane for bicycling questions), and the vehicular volume of the roadway designated as either low or high.

Two of the factors had three levels (speed limit: 25 mph, 35 mph, or 45 mph; and number of lanes: two lanes, three lanes, or four lanes), while two of the factors had two levels (presence of facility: yes or no; and volume of the roadway: low or high). This theoretically resulted in a total of 36 possible scenarios for walking and 36 possible scenarios for bicycling. However, we removed scenarios that did not exist or were rare in Denver (e.g. 45-mph roadways with two lanes and low volumes), resulting in a total of 20 walking scenarios and 20 bicycling scenarios.

Each parent respondent answered five random walking scenarios and five random bicycling scenarios. Each scenario included a picture of a roadway and asked if the parent would let their child/children walk or bike to school along the roadway (Figure 9.1). The available responses were "No", "Yes, with trusted adult supervision", and "Yes, without adult supervision". Respondents also had the ability to leave open-ended comments after the scenarios were presented. We then asked respondents about the amount of physical activity their child/children get on a weekly basis and gave them the choice to enter an email address for the chance to win one of ten $50 gift cards that were offered as a survey incentive.

Of the 1,298 survey respondents, 924 provided complete responses. These 924 complete parent responses accounted for 1,331 children. There was an appropriate distribution of responses across grade levels and gender, and the majority of surveys were completed for one or two children (Table 9.1 and Figure 9.2).

8. Would you allow your child to use this roadway **on foot** to get to school?



25 mph Speed Limit
3 Lanes
Sidewalks
Low Vehicle Volume

34. Would you allow your child to use this roadway **on bike** to get to school?

35 mph Speed Limit
2 Lanes
Bike Lanes
Low Vehicle Volume

Figure 9.1 Picture-based Roadway Scenarios from the Survey We Administered to Parents

Table 9.1 Survey Response Descriptive Statistics

Gender	
Male	667
Female	658
Other	4
Number of Children for each Survey	
1	441
2	342
3	54
4	11
Minutes you would like your child to be physically active during school	
20	9
30	96
40	117
50	45
60	322
60+	244
Days your child got 60 minutes of physical activity in the last week	
0	7
1	19
2-3	148
4-5	314
6+	351

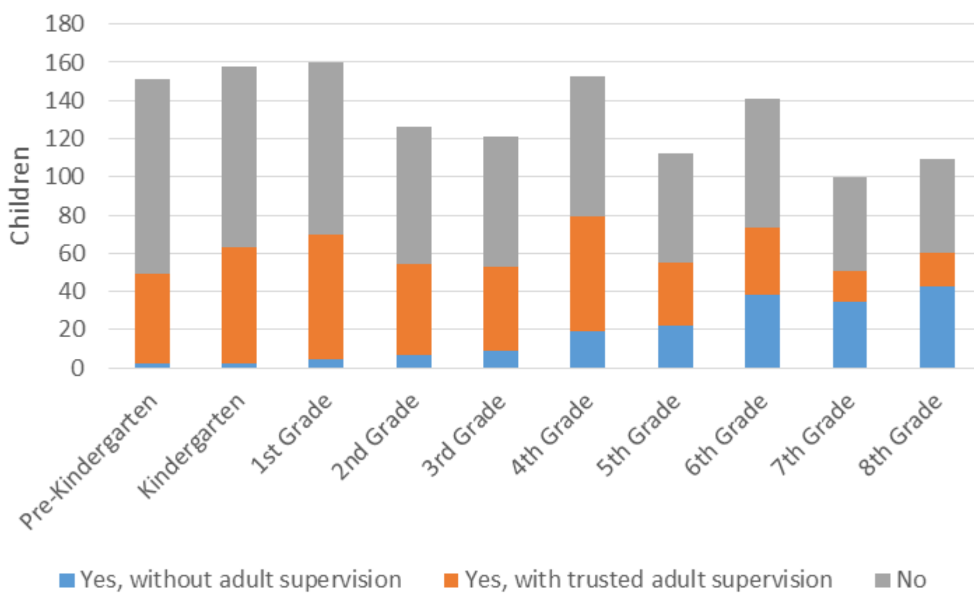


Figure 9.2 Number of Parental Allowance Responses from the Survey for All Roadway Scenarios by Grade Level

9.2 Population and Built Environment Data

We collected age-based population data on the block group level from the 2015 American Community Survey via the National Historical Geographic Information System (NHGIS) (Manson, Schroeder, Van Riper, & Ruggles, 2017). The Denver Open Data Catalog provided the sidewalk network, roadway network, and off-road trail network in polyline shapefile format. The Denver Regional Council of Governments' (DRCOG) Regional Data Catalog provided traffic volumes and school locations in point shapefile format. We created the bike lane network in polyline shapefile format based on the location of bike lanes per Google Maps, satellite imagery, and Google Street View.

10. METHODS

The goal of this work was to create a trip-suppression model based on parental perceptions of roadway characteristics to determine which personal and street-level design characteristics impact trip suppression. We then integrated trip-suppression rates derived from the survey with the upper limit of trip frequencies – the number of expected trips under ideal conditions as derived from a GIS network analysis – to determine the number of active transport trips to school that are suppressed because of road safety concerns, how routes are altered, and which built environment characteristics suppressed trips are associated with.

To accomplish these goals, we identified the pertinent roadway characteristics for each roadway segment and used survey results to determine the percentage of trips we would expect to be suppressed on each segment due to traffic safety concerns. We then defined children's homes as origins and their closest school as the corresponding destination, deriving optimal trip routes through a closest facility network analysis. We used these optimal routes to derive the upper limit of trips that would theoretically utilize each roadway segment. After accounting for the impact of network connectivity on walking levels, we combined the trip suppression rates (from the survey) with the upper limit of trips (from the network analysis) for each roadway segment and used this to answer our research questions.

10.1 Suppression Rates

With logistic regressions, we created the trip-suppression model derived from the parental perceptions survey to determine which factors are associated with trip suppression. We first used a dichotomous dependent variable where allowance both with and without adult supervision were categorized together. We examined grade level, gender, and street-level design characteristics (e.g., posted speed limit, sidewalks, bike lanes, number of lanes, and vehicle volumes) with this model to establish their relationship with trip suppression rates. When next exploring the impact of adult supervision, we accounted for all students in a single logistic regression model for walking and a single logistic regression for bicycling using "Yes, with trusted adult supervision" and "Yes, without adult supervision" as the dichotomous dependent variables.

We next determined what percentage of trips would be suppressed due to road safety concerns for different roadway scenarios. We coded all 40 roadway scenarios featured in the survey based on their four predictor variables, while designating the outcome variable as the percentage of parents that would not allow their children to use the roadway. Since the diversity of actual Denver roads exceeded what we were able to reasonably include in the parental survey, we created a linear regression using the four roadway characteristics as predictor variables and the percentage of disallowance as the outcome variable. Using these linear regressions, we then took the street-level design characteristics for each scenario not featured in the survey and derived the corresponding suppression rate.

10.2 Network Analysis

We deduced the maximum number of trips that would occur under ideal conditions through a network analysis in GIS. We utilized all public elementary and middle schools in Denver for analysis. DPS does not provide busing for elementary students who live less than a mile from their school. To capture these populations that would be more apt to pursue active modes of transportation, we created a Euclidian distance one-mile buffer (i.e., an as-the-crow-flies buffer instead of a network buffer) around each of the elementary and middle schools and designated this as the study area. The study area included the majority of Denver, except for the far northeast portion of the city comprising the airport.

After clipping the roadway centerlines to the study area, we removed any limited access highways and merged off-road trails into the layer. All divided roadways were represented by one line instead of two. We avoided edge issues by including roadways in neighboring municipalities that fell within one mile of a DPS school and ensuring that all stray road segments were connected to the larger network. Finally, we cleaned access points around the schools so that students in the model could approach their school from the same side they would in reality.

To account for explanatory roadway characteristics, we utilized speed limits and the number of lanes provided from the City and County of Denver's roadway layer, after checking for and amending any errors. We utilized vehicle volumes provided by DRCOG, with any roadway having more than 1,000 vehicles per day being designated as high volume (Program, 2014). We used the City and County of Denver's sidewalk layer to manually identify roadways with or without a sidewalk. Google Maps, satellite imagery, and Google Street View were utilized to identify roadways with bike lanes. Roadways with no sidewalks/bike lanes were given a value of zero; roadways with a sidewalk/bike lane on one side were given a value of one; and roadways with a sidewalk/bike lane on both sides were given a value of two.

Once the roadway network was complete, we accounted for origins and destinations. Destinations were defined as public DPS elementary and middle schools within the City and County of Denver. Origins were based on child populations from the 2015 American Community Survey. For each census block group located within the study buffer, we created one random point for each child living in that census block group using ESRI's "Create Random Points" tool. This tool creates a specified number of random point features inside a constraining polygon, which is defined by the user. We created random points only in residential zones to realistically represent home origins. While it would be ideal to know exactly how many attending children live within one mile of each school and the home address of those children, that information was not available due to privacy concerns.

There were 112,648 children in Denver and 23,490 in neighboring municipalities included in the analysis. The number of children included in the analysis is higher than the number of children attending DPS schools, because the analysis also included children living in Denver that attend private schools or are home schooled. Also, some children living in Denver included in the analysis may be attending schools in neighboring municipalities or may be too young to attend school. The largest of the 587 block groups had 3,326 children, while 23 block groups had no children. Census block groups with no children consisted of either undeveloped land or land uses other than residential.

We then ran a closest facility network analysis using GIS. This takes the origin (child) and finds the shortest route to their closest destination (school). While pedestrians and bicyclists often do not use the shortest available path because of road safety and comfort concerns, we wanted to start with a baseline of how many trips could occur under ideal conditions and then derive the number of suppressed trips based on that value (Krizek, El-Geneidy, & Thompson, 2007). Alternatively, if we derived the number of trips being suppressed because of safety concerns from a trip count weighted on traffic safety concerns, this would result in multicollinearity issues.

Children's routes began at their closest street. Denver is a predominantly flat city located on the western edge of the Great Plains. Therefore, elevation was not factored into the network analysis. The unidirectional operations of one-way streets were accounted for in the bicycling analysis but were not accounted for in the pedestrian analysis. We integrated the impact of the built environment on active transportation levels into the network analysis by accounting for street network design via intersection density, which past research has shown as significantly associated with the likelihood of kids walking and biking to school (Schlossberg, Greene, Phillips, Johnson, & Parker, 2006). In other words, neighborhoods with higher intersection densities are expected to have more walking and biking and therefore may have more trips suppressed by safety concerns. We did not account for crime because of mixed findings in terms of the relationship between objective crime and walking levels, mainly due to more walkable environments attracting different types of crimes (Foster et al., 2014).

The network analysis resulted in 136,138 routes, as all origin/destination pairs were successfully connected. We then derived the number of routes that utilized each roadway segment within the City and County of Denver. This resulted in the total number of children who could be expected to walk or bike on each segment under ideal conditions, assuming that children would be walking or biking within a mile to their closest school.

10.3 Suppressed Trips

Now that each roadway segment had a set of roadway characteristics, a corresponding percentage of parents that would not allow their child to walk or bike, and the total number of possible trips under ideal conditions, we were able to: 1) determine how many children encounter roads of varying levels of suppression, 2) determine how their routes were impacted, 3) estimate how many trips were suppressed, and 4) explore which network characteristics were associated with suppressed trips. To determine how routes are impacted, we treated road segments with a suppression rate of 50% or greater as barriers. In other words, when at least half of parents identified a road segment as unsafe, we considered that segment as a barrier worth avoiding. To estimate how many trips are suppressed, we multiplied the number of ideal trips by the percentage of disallowance to derive the number of trips that would theoretically be suppressed because of traffic safety concerns. This was done for each roadway segment in the study area. Doing so allowed us to perform spatial analysis to understand where there are high numbers of suppressed trips and which built environment characteristics are associated with those high numbers of suppressed trips.

11. RESULTS

We first utilized logistic regressions to examine the impact of demographic and roadway characteristics on parental allowance for children's walking and biking school trips. We then employed linear regressions to explore the percentage of trips that could expect to be suppressed due to traffic safety concerns for a variety of different scenarios. Finally, we integrated these trip suppression rates with the upper limit of modal frequencies derived through GIS network analyses to discover areas of Denver that have high levels of trip suppression and found associated built environmental characteristics.

11.1 Trip Suppression Factors

Typically, the roadway characteristics utilized in our models (i.e., posted speed limits, number of lanes, presence of active transport facilities, and vehicular volumes) would be collinear. However, because a wide range of roadway scenarios were chosen for the survey instrument, multicollinearity was avoided. A variance inflation factor (VIF) threshold of 1.46 for the variables signaled low multicollinearity. A VIF of 5.0 or above is typically indicative of multicollinearity issues (Vatcheva, Lee, McCormick, & Rahbar, 2016).

When simply looking at parental allowance in a binary fashion (i.e., allowance both with and without adult supervision are categorized together) for all children captured by the survey, gender was not significantly related to parental allowance for either walking or bicycling, but the variable did strengthen the model based on a lower AIC (Table 11.1). Other than the number of siblings and the days of physical activity in the bicycling model, all other explanatory variables were significant. The presence of sidewalks was a strong predictor for the walking model, with a 14.079 odds ratio interpreted as parents being approximately 14 times more likely to allow their child to walk on a roadway with sidewalks present than a roadway without sidewalks, with all other factors held constant. Vehicle volumes and the presence of bicycle facilities (bicycle lanes) were strong predictors for the bicycling model. We utilized the grade variable by individual grade level, so a 1.078 odds ratio means that a fifth-grade student would be 1.078 times more likely to be allowed to walk than a fourth-grade student, with all other factors held constant. Because units are not standardized, we are not able to make direct comparisons between odds ratios of different variables.

Table 11.1 Parental Allowance Logistic Regression Odds Ratios

	Walk $R^2 = 0.338$; n = 6,655		Bike $R^2 = 0.223$; n =6,655	
	Odds ratio	p-value	Odds ratio	p-value
Grade	1.078	<0.0001	1.178	<0.0001
Gender *(male=0)*	0.940	0.3233	0.896	0.0580
Speed (*10 mph increments*)	0.402	<0.0001	0.581	<0.0001
Lanes	0.751	<0.0001	0.576	<0.0001
Facilities	14.079	<0.0001	2.502	<0.0001
Volume (*low/high*)	0.445	<0.0001	0.297	<0.0001
Number of Siblings	0.808	<0.0001	1.045	0.2790
Days of Physical Activity	1.143	0.0003	1.052	0.1399

When we further parse the results by examining how factors are correlated in terms of whether parents reported trusted adult supervision as required, findings suggest that both types of allowances follow similar patterns (Table 11.2). Namely, the presence of sidewalks remains an important factor in terms of walking allowance. In terms of biking allowance, vehicle volume remains an important factor. These results suggest that those factors identified as important in the models not accounting for supervision are also important when supervision is accounted for, with grade level becoming a stronger predictor, as we would expect.

Table 11.2 Parental Allowance Logistic Regression Odds Ratios based on the Presence of Parent Supervision

	Walk R^2 = 0.452; n = 6,655	Bike R^2 = 0.374; n = 6,655
Grade	1.814***	1.697***
Gender *(male=0)*	0.823**	0.880
Speed (*10 mph increments*)	0.642***	0.629***
Lanes	0.863**	0.795***
Facilities	4.177***	1.055
Volume (*low/high*)	0.533***	0.447***

* *p<0.10*
** *p<0.05*
*** *p<0.01*

11.2 Trip Suppression Rates

Once we understand which demographic and street-level design factors are related to trip suppression, we can begin to explore how many children in Denver are impacted by trip suppression and how that trip suppression impacts route choice. Since we did not detect any non-linear relationships, linear regression was used in this analysis. We created a linear regression (Table 11.3) with the results from the survey to derive a mode choice model that outputs the rate of trip suppression due to traffic safety concerns for a variety of different roadway scenarios (Table 11.4). Suppression rates for bicycling were generally higher than for walking, as parents were less willing to let their children bicycle to school. The presence of facilities can be viewed as having a large impact on walking, while vehicle volume has a large impact on bicycling.

Table 11.3 Linear Regression Coefficients for Trip Disallowance Derived from Survey Results

	Walk R^2 = 0.9654; n=20	Bike R^2 = 0.9227; n=20
Intercept	0.037	-0.076
Speed (mph)	0.015***	0.010***
Lanes	0.046*	0.105***
Facilities	-0.248***	-0.086***
Volume	0.131***	0.230***

* *p<0.10*
** *p<0.05*
*** *p<0.01*

Suppression rates varied for different roadway scenarios based on survey and linear regression model results. While parents reported that only 5.9% of walking trips would be suppressed on a low-volume, 25 mph, three-lane road with sidewalks, parents reported that the same road without sidewalks would see 55.4% of walking trips suppressed (Figure 11.1). Parents reported that for a high-volume, 25 mph, three-lane road with sidewalks, 18.9% of walking trips would not be allowed. Here we can see that the change in facilities had a much larger impact on allowance than the change in vehicle volume. Also, vehicle volumes have a greater impact on trip suppression for bicycling than for walking.

Table 11.4 Percentage of Trips Suppressed Based on Survey and Linear Regression (Variables Held at 3 Lanes, Presence of Facilities, and Low Volume)

	25 mph		35 mph		45 mph	
	Walk	Bike	Walk	Bike	Walk	Bike
Lanes						
2	1.3%	21.2%	16.4%	31.2%	31.6%	41.2%
3	5.9%	31.7%	21.0%	41.7%	36.2%	51.7%
4	10.5%	42.2%	25.6%	52.2%	40.8%	62.2%
Facilities						
No	55.4%	48.9%	70.6%	58.9%	85.7%	68.9%
Yes	5.9%	31.7%	21.0%	41.7%	36.2%	51.7%
Volume						
Low	5.9%	31.7%	21.0%	41.7%	36.2%	51.7%
High	18.9%	54.7%	34.1%	64.7%	49.2%	74.7%

- 25 mph
- 3 Lanes
- Sidewalks
- Low Volume

5.9% of child walking trips will not be allowed according to parent responses.

- 25 mph
- 3 Lanes
- No Sidewalks
- Low Volume

55.4% of child walking trips will not be allowed according to parent responses.

- 25 mph
- 3 Lanes
- Sidewalks
- High Volume

18.9% of child walking trips will not be allowed according to parent responses.

- 25 mph
- 3 Lanes
- Bike Lanes
- Low Volume

31.7% of child biking trips will not be allowed according to parent responses.

- 25 mph
- 3 Lanes
- No Bike Lanes
- Low Volume

48.9% of child biking trips will not be allowed according to parent responses.

- 25 mph
- 3 Lanes
- Bike Lanes
- High Volume

54.7% of child biking trips will not be allowed according to parent responses.

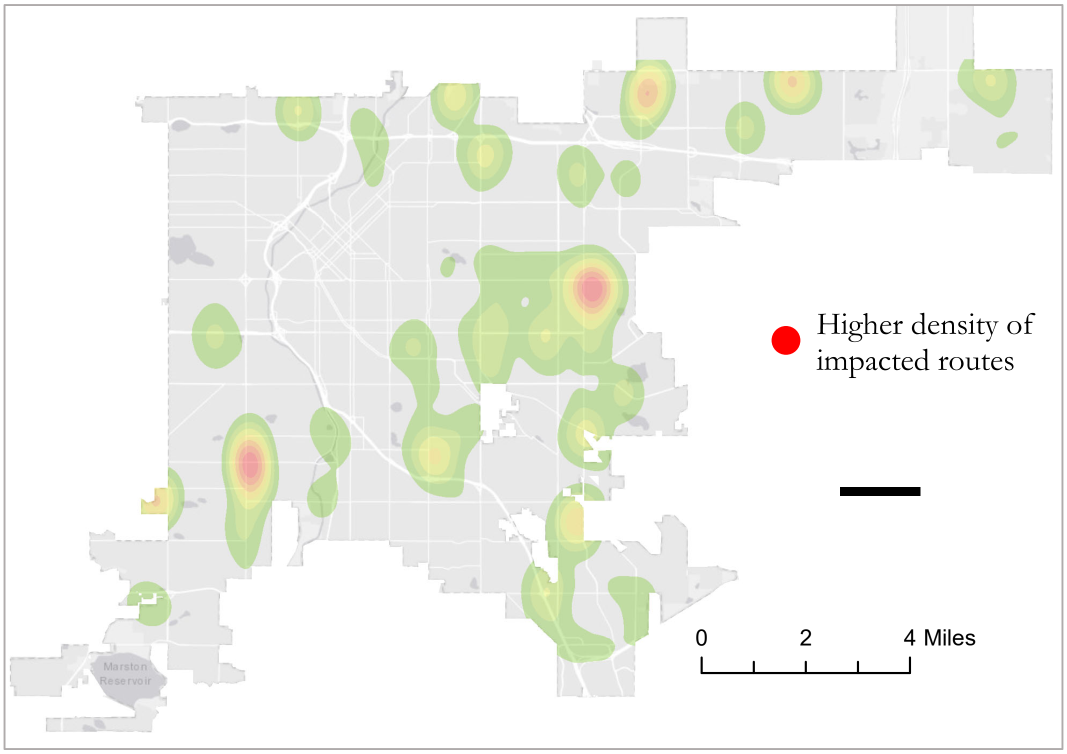
Figure 11.1 Examples of Parent-reported Trip Disallowance for Different Walking and Biking Roadway Scenarios

We next identified to what extent children are encountering these roads with high levels of disallowance. When taking the shortest route from home to school, more children in Denver encounter roads parents have deemed unsafe for bicycling than encounter roads that parents have deemed unsafe for walking. Approximately 2.3% of children in Denver would encounter a road with 75% disallowance or greater for walking (a road that is perceived as particularly unsafe), assuming they take the shortest route to school (Table 11.5). However, 31.8% of children in Denver would encounter a road with 75% disallowance or greater for bicycling under that same assumption. For roads with a 50% disallowance (still perceived as relatively unsafe), more than half of children in Denver would encounter those roads for a bicycling trip and 12% would encounter them for walking trips. This converts to tens of thousands of trips each day, showing that the issue is widespread throughout Denver.

Table 11.5 Percentage of Children Encountering Roads with Varying Disallowance Rates

	25% Disallowance	50% Disallowance	75% Disallowance
Walk	40.5%	12.2%	2.3%
Bike	64.9%	61.4%	31.8%

Children who encounter roads perceived as unsafe for walking – specifically those roads more than half of parents would not allow their child to walk on – are primarily found in two different areas in Denver: an area with sidewalk gaps (the top-right concentration) and an area near a high-volume, high-speed, and wide boulevard (the bottom-left concentration) (Figure 11.2). Children who encounter roads perceived as unsafe for bicycling are similarly found near that same high-volume, high-speed, and wide boulevard; while a concentration in the northeast is the result of high concentrations of children, a curvilinear roadway network, and a lack of bicycle facilities. It is apparent that, in general, there are more children who encounter roads that parents would not allow them to bicycle on than children who encounter roads that parents would not allow them to walk on. The neighborhoods with the highest number of children who encounter roads perceived as unsafe have median household incomes that are 6.2%, 15.1%, and 46.7% below average for Denver.



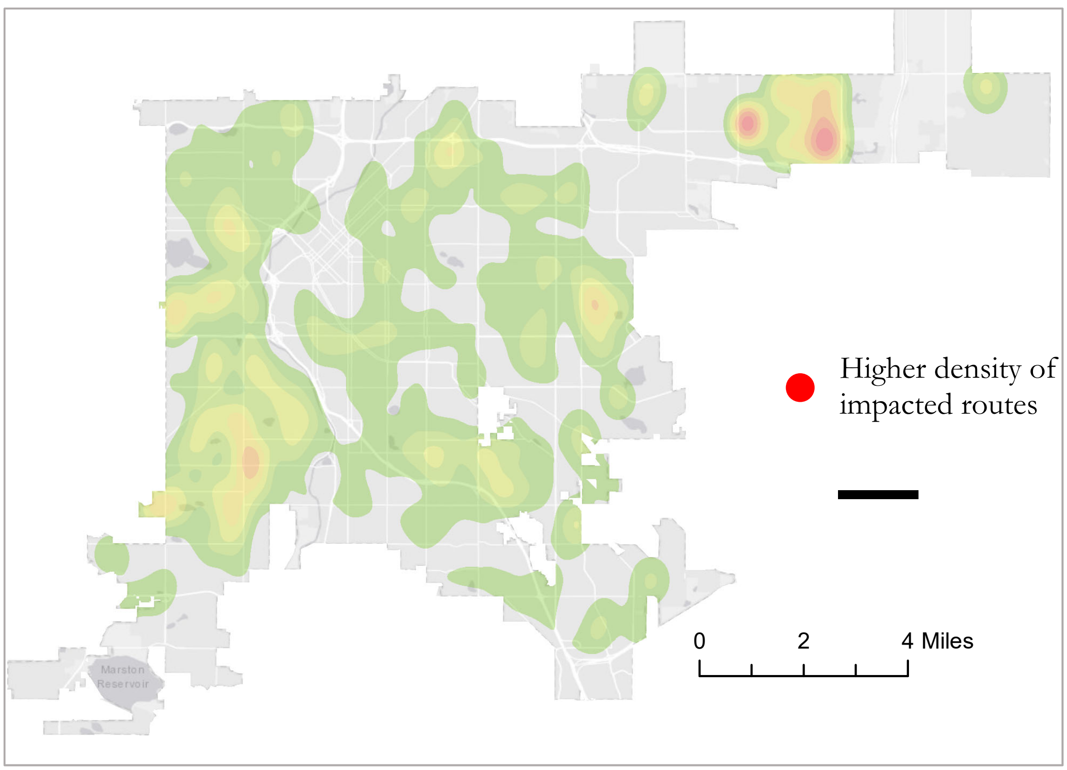


Figure 11.2 Densities of Children with Negatively Impacted Routes for Walking (Top) and Bicycling (Below)

However, if an in-place grid network presents pedestrians and bicyclists with different route options, children may be able to simply avoid these roads perceived as unsafe by using parallel streets. How much farther would children's trips be if these roads perceived as unsafe were not utilized? To answer this inquiry, we reran the network analysis after the roads perceived as unsafe – particularly those with greater than 50% disallowance – were weighted so they would be discouraged according to parental traffic safety concerns. We then compared the trip lengths under ideal conditions with those when roads perceived as unsafe were accordingly discouraged.

For walking trips, the average trip length across the city increased from 2,728 feet under optimal conditions to 2,937 feet once roads perceived as unsafe were discouraged. For bicycling trips, the average trip length increased from 2,728 feet under optimal conditions to 3,763 feet once roads perceived as unsafe were discouraged. Citywide, about 4,274 children were pushed out of a half-mile walk shed when road safety perceptions were accounted for, while 23,429 children were pushed out of a half-mile bike shed. The greatest increases in distance were concentrated in neighborhoods with curvilinear tributary roadway networks or limited route options because of barriers, resulting in large increases in trip distance (upwards of an additional 5,228 feet to avoid roads perceived as unsafe in the curvilinear tributary neighborhood). Areas with grid networks that saw large percentages of roads perceived as unsafe did not have similarly large increases in trip distance because of the ability for pedestrians and bicyclists to select alternate routes with little additional distance.

11.3 Number of Suppressed Trips

We then integrated the results from the mode choice model with the number of total possible trips to derive the number of trips suppressed due to road safety concerns for roadways in Denver, and identified which roadways have the most suppressed trips (Table 11.6). We focused on roads with greater than 25% disallowance, because these roads are perceived as unsafe and are most likely in need of amendment. While some roads with less than 25% disallowance had high numbers of suppressed trips, it was only because of high levels of ideal exposure, not because of a lack of perceived safety. Therefore, these roads were not considered. The high number of low-speed local roads in Denver's grid networks resulted in a relatively low mean of suppressed trips per road segment. We utilize spatial analysis techniques in the Discussion section to explore where these road segments with high numbers of suppressed trips are located.

Table 11.6 Number of Suppressed Trips per Road Segment

	Min	Max	Mean	SD
Walk	0	272	1.60	5.90
Bike	0	528	7.11	20.59

12. DISCUSSION

This section presents a spatially oriented, rather than statistical, analysis of where roadways with high numbers of suppressed trips are located. Walking trip suppression and bicycling trip suppression displayed similar spatial patterns within the study area. We determined areas of high trip suppression by ranking them and looking for patterns in the highest rankings. We then found high numbers of suppressed trips primarily either near a connection through a barrier in the roadway network or near a school. The barrier connections were at impediments with limited pathways over or under them (e.g., limited access highways or bodies of water), for which high rates of trips would optimally funnel through the few available connections. Because these barrier connections primarily serve vehicles, they are usually wide, high-speed roadways. Therefore, while such connections are vital to both motorists and non-motorists, the connections are often built to accommodate vehicles and present non-motorists with an option that is very often perceived as unsafe (Figure 12.1). We found only a few examples of high numbers of suppressed trips at barrier connections because children often have schools within their own neighborhoods that are closer than those on the other side of the barrier.

Figure 12.1 Examples of Barrier Connections with High Trip Suppression (Lincoln Street under I-70 on the left; Dunkirk Street over First Creek on the right)

There were also high rates of trip suppression on roadways near schools. These roadways can be broken into two categories: those in tributary curvilinear loop networks and those in grid networks. While the majority of Denver consists of gridded networks, three of the top six areas for suppressed walking trips near schools and two of the top six areas for suppressed biking trips near schools are found in a neighborhood in northeast Denver with a predominately tributary curvilinear loop roadway network. This network consists of curved local streets that channel onto collector or arterial streets. While pedestrians and bicyclists in grid networks have the option to use a variety of roadways to get to their destination, non-motorized users in curvilinear loop networks typically must channel to a main road that has been prioritized for vehicles. While the roads in this neighborhood may not be perceived to be as dangerous as some in central Denver (the collectors and arterials typically have two sidewalks, do not have bike lanes, are signed at 25 mph or 30 mph, have four vehicular lanes, and are high volume), the high trip suppression rates are being driven by the fact that trips are concentrated on these main roads because of the street network configuration (Figure 12.2).

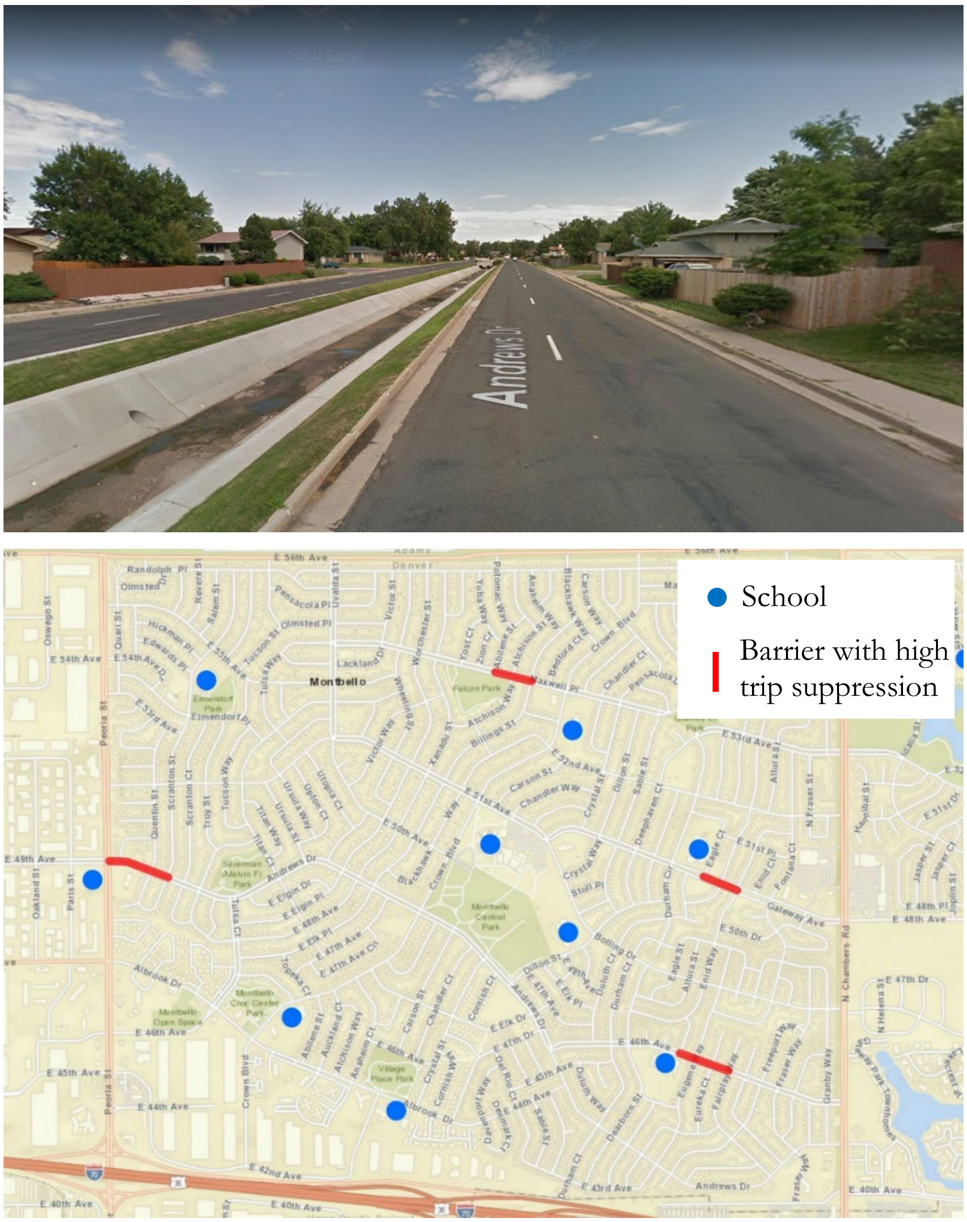


Figure 12.2 Examples of High Trip Suppression around a School in a Curvilinear Loop Network (Blue dots are schools; image is of Andrews Drive)

Relatively few areas with high trip suppression were found in the grid network. High trip suppression roadways found in the grid network typically occurred when a school was placed on or near a major road (Figure 12.3). High numbers of suppressed trips were found when schools were placed next to major roads outside of the grid network as well. While pedestrians and bicyclists in a grid network typically have options in regard to which roads they utilize, siting a school directly on an arterial can force them to use an unsafe road, thereby dissuading walking or biking trips.

Figure 12.3 Examples of High Trip Suppression around Schools near Major Roads (Sheridan Boulevard on the left; Monaco Parkway on the right)

13. CONCLUSIONS

By combining trip suppression rates derived from a perception survey with the upper limit of trip frequencies from a GIS network analysis, our tool allows us to identify areas where trips are suppressed because of road safety concerns. Although identified areas are not technically objectively unsafe, only perceived as unsafe, identifying such areas will hopefully aid in the identification of road safety issues before they occur.

We find that, for all children, both with and without adult supervision, sidewalks are a strong predictor in terms of walking allowance, and vehicle volumes are a strong predictor in terms of biking allowance. Parents may be more concerned with the presence of vehicles for biking rather than walking because their child would likely be biking in the street. Gender of the child has a weak relationship with allowance. When we parse the results by age, sidewalks consistently remain an important factor for walking allowance. When we look at the role adult supervision plays, we see sidewalks (for walking) and vehicle volumes (for biking) remain important factors, while grade level becomes a stronger predictor.

Examining the pervasiveness of these issues, we find that over 61% of children encounter a road perceived as unsafe (defined as 50% or greater parent disallowance) for biking and over 12% encounter a similar road for walking. This indicates that the problem of perceived safety is prevalent across Denver. While many children's routes were not substantially altered because of the trip suppression, some neighborhoods experienced large increases in the distance that must be travelled. Children in some neighborhoods needed to add an additional mile onto their route to avoid such roads.

Areas with high numbers of suppressed trips were heavily concentrated around schools in parts of the city with tributary curvilinear loop networks. Grid networks seem to help alleviate high numbers of suppressed trips, provided that the school is not sited on or very near a major road. There are also high numbers of suppressed trips present at barrier connections. The segments of high trip suppression are typically not great in length, meaning that it may only take one block of conditions perceived as unsafe to dissuade a pedestrian or bicycle trip from occurring.

Primary limitations of the work are focused on the origin and destination location of the school trips employed in the model. Because of privacy issues, we could not account for the actual trip of each student, and instead assumed that children would be most likely to attend their closest school. This is an assumption we know to be imperfect because of Colorado's open enrollment policy. While this may have impacted the implementation of the tool, the theoretical methodology developed is still sound. Future work could improve upon the current approach by examining areas with clearer origins and destinations. Furthermore, the number of parent respondents who took the survey in Spanish was low (3.6%) relative to the number of reported Spanish speaking students in DPS (36.8%). While we believe that some Spanish speakers took the survey in English, specifically concentrating on these populations in future efforts may result in more representative outcomes.

The decision to allow a child to walk or bike is typically influenced by a combination of street design variables. Future work may explore different explanatory variables utilized for the model. While we used more explanatory roadway-characteristic variables than past studies (Cho et al., 2009; Nevelsteen et al., 2012b; Schneider et al., 2004), roadways are complex, and more variables may lend further strength to our models. For the sake of this work, we used a combination of variables – including the number of lanes, posted speed limits, and vehicle volumes – as an indicator of the exposure to risk a child would encounter when crossing a road. However, in terms of crossings, there are other factors (e.g., signalization, phasing, crosswalks, medians, etc.) that would also be important to account for. Sidewalk conditions also vary, and these varying conditions would be important to include in future models. Specifically for Denver, many neighborhoods have two-foot-wide sidewalks, for which parents may have varying perceptions of road safety relative to current five-foot-wide sidewalk standards. Furthermore, examining the impact of actual vehicle speeds instead of simply assuming signed speed limits is reflective of operating conditions that may improve future models. The vehicle volume factor could account for whether peak hour crests occur during times when children would be expected to be walking or biking on each road. Finally, future work may also account for school zones, which could improve traffic safety perceptions near schools. School zones in Denver are typically signed at 20 mph, but major roads use speed limits of up to 40 mph in school zones, highlighting the bias toward motor vehicles and against non-motorized trips.

In terms of macro-scale perspectives of the work, future analysis could account for varying land uses and other pertinent built environment factors. While we were only concerned with trips to and from school, and it was therefore appropriate to only account for this one specific land use (Ewing, Schroeer, & Greene, 2004), more holistic future examinations would be wise to account for the presence of other land uses and destinations. Moreover, we were primarily concerned with suppression due to perceived road safety issues in this report; related built environment factors that may have an impact on suppression, such as street trees and building density, would be worth exploring in a future work. The impact of crime on levels of walking and biking could also be accounted for but would necessitate a thorough examination of the types of crime occurring relative to the land uses throughout the study area. For example, while violent crime in residential neighborhoods may dissuade walking and biking, high rates of shoplifting may signal a strong commercial area that could have high levels of walking and biking (Foster et al., 2014). Such a thorough analysis of crime in Denver was outside the purview of the current iteration of the work. Results also hinted at equity issues, namely that lower-income or minority neighborhoods may have to more frequently deal with traffic safety issues, more so than their more affluent counterparts. The neighborhoods that had the highest number of children who encounter roads perceived as unsafe were found to have median household incomes below average for Denver.

Future work could see integration of this trip suppression tool into a proactive safety analysis by similarly identifying areas with high trip suppression. Results from such a proactive analysis could be compared with a traditional reactive safety analysis. Outcomes from the two analyses would be expected to vary. We would hope to identify areas with high rates of trip suppression but low objective crashes or injuries. These would be areas with road safety issues that dissuade non-motorized users enough to preclude objective outcomes, therefore have thus far been neglected. It is recommended that planners and engineers utilize such analysis approaches and also deploy recommendations from this work, namely employing grid networks, siting schools – and other locations that children may be expected to frequent – on more minor roads, and ensuring that there are pedestrian and bicycle facilities present where there are vital connections across barriers.

Pedestrian and bicycle trips that have been suppressed because of traffic safety concerns can be an important indicator of road safety in our transportation systems. The tool developed in this report allows for the identification of roadways with high levels of suppressed trips in terms of street-level design characteristics. This approach allows for the methodology to be applied widely, enabling utilization by academics and practitioners alike. Through the application of this tool in Denver, we identified important personal and design characteristics that act as predictors of trip suppression, as well as the importance of grid networks, barrier connections, and destination siting. By identifying these areas with high numbers of suppressed trips, and by enabling others to do the same, we have facilitated the proactive identification of traffic safety issues on our roadways.

14. REFERENCES

Administration, F. H. (2006). *Pedestrian and Bicyclist Safety*. In (Vol. FHWA-HRT-05-090).

Bellemans, T., van Bladel, K., Janssens, D., Wets, G., & Timmermans, H. (2009). "Measuring and Estimating Suppressed Travel with Enhanced Activity-Travel Diaries." *Transportation Research Record*(2105), 57-63. doi:10.3141/2105-08

Board, T. R. (2001). *Statistical Methods in Highway Safety Analysis*. In (Vol. NCHRP Synthesis 295). Washington, D.C.

Cho, G., Rodriguez, D., & Khattak, A. (2009). "The role of the built environment in explaining relationships between perceived and actual pedestrian and bicyclist safety." *Accident Analysis and Prevention, 41*(4), 692-702. doi:10.1016/j.aap.2009.03.008

Ewing, R., Schroeer, W., & Greene, W. (2004). "School Location and Student Travel Analysis of Factors Affecting Mode Choice." In (Vol. 1895, pp. 55-63): *Transportation Research Record.*

Foster, S., Knuiman, M., Villanueva, K., Wood, L., Christian, H., & Giles-Corti, B. (2014). "Does walkable neighbourhood design influence the association between objective crime and walking?" *International Journal of Behavioral Nutrition and Physical Activity, 11*. doi:10.1186/s12966-014-0100-5

Jacobsen, P., Racioppi, F., & Rutter, H. (2009). "Who owns the roads? How motorised traffic discourages walking and bicycling." *Injury Prevention, 15*(6), 369-373. doi:10.1136/ip.2009.022566

Krizek, K., El-Geneidy, A., & Thompson, K. (2007). "A detailed analysis of how an urban trail system affects cyclists' travel." *Transportation, 34*(5), 611-624. doi:10.1007/s11116-007-9130-z

Larsen, K., Buliung, R., & Faulkner, G. (2013). "Safety and School Travel: How Does the Environment Along the Route Relate to Safety and Mode Choice?" *Transportation Research Record*(2327), 9-18. doi:10.3141/2327-02

Manson, S., Schroeder, J., Van Riper, D., & Ruggles, S. (2017). *IPUMS National Historical Geographic Information System: Version 12.0*. In: Minneapolis: University of Minnesota.

Nevelsteen, K., Steenberghen, T., Van Rompaey, A., & Uyttersprot, L. (2012a). "Controlling Factors of the Parental Safety Perception on Children’s Travel Mode Choice." In (Vol. 45, pp. 39-49): Accident Analysis and Prevention.

Organization, W. H. (2000). *Transport, environment and health*. In. Copenhagen, Denmark: WHO Regional Office for Europe.

Program, C. L. R. (2014). *Basics of a Good Road*. In (Vol. CLRP No. 14-04): New York Local Technical Assistance Program.

Qin, X., Ivan, J., & TRB. (2001). "Estimating pedestrian exposure prediction model in rural areas." *2001 Trb Distinguished Lecture, Pt 1 - Bicycle and Pedestrian Research, Pt 2*(1773), 89-96.

Schlossberg, M., Greene, J., Phillips, P., Johnson, B., & Parker, B. (2006). "School trips - Effects of urban form and distance on travel mode." *Journal of the American Planning Association, 72*(3), 337-346. doi:10.1080/01944360608976755

Schneider, R., Ryznar, R., & Khattak, A. (2004). "An accident waiting to happen: a spatial approach to proactive pedestrian planning." *Accident Analysis and Prevention, 36*(2), 193-211. doi:10.1016/S0001-4575(02)00149-5

Vatcheva, K. P., Lee, M., McCormick, J. B., & Rahbar, M. H. (2016). "Multicollinearity in Regression Analyses Conducted in Epidemiological Studies." In (Vol. 6, pp. 227-236): *Epidemiology*.

Waldheim, N., Wemple, E., & Fish, J. (2015). *Applying Safety Data and Analysis to Performance-Based Transportation Planning*. In (Vol. FHWA-SA-15-089).

York, G. (2007). "Cars conquering the bicycle kingdom." In: Globe and Mail.

Zegeer, C., Nabors, D., Gelinne, D., Lefler, N., & Bushell, M. (2010). *Pedestrian Safety Strategic Plan: Recommendations for Research and Product Development*. In (Vol. FHWA-10-035).