CHILDREN AT RISK: A COMPARISON OF CHILD PEDESTRIAN TRAFFIC COLLISIONS IN SANTIAGO, CHILE AND SEOUL, SOUTH KOREA

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ABSTRACT

Objective: We examine and compare pedestrian-vehicle collisions and injury outcomes involving school-age children between 5 and 18 years of age in the capital cities of Santiago, Chile and Seoul, South Korea.

Methods: We conduct descriptive analysis of the child pedestrian-vehicle collision (P-VC) data (904 collisions for Santiago, and 3,505 for Seoul) reported by the police between 2010 and 2011. We also statistically analyze factors associated with child P-VCs, both by incident severity and age group using three regression models: negative binomial, probit, and spatial lag models.

Results: Descriptive statistics suggest that child pedestrians in Seoul have a higher risk of being involved in traffic crashes than their counterparts in Santiago. However, in Seoul a greater proportion of children are unharmed as a result of these incidents, while more child pedestrians are killed in Santiago. Younger children in Seoul suffer more injuries from P-VCs than in Santiago. The majority of P-VCs in both cities tend to occur in the afternoon and evening, at intersections in Santiago and at midblock locations in Seoul. Our model results suggest that the resident population of children is positively associated with P-VCs in both cities, and school concentrations apparently increase P-VC risk among older children in Santiago. Bus stops are associated with higher P-VCs in Seoul, while subway stations relate with higher P-VCs among older children in Santiago. Zone-level land use mix was negatively related to child P-VCs in Seoul, but not in Santiago. Arterial roads are associated with fewer P-VCs, especially for younger children in both cities. A share of collector roads is associated with increased P-VCs in Seoul, but fewer P-VCs in Santiago. Hilliness is related to fewer P-VCs in both cities. Differences in these model results for Santiago and Seoul warrant additional analysis as do the differences in results across model type (Negative Binomial versus Spatial Lag models).

Conclusions: To reduce child P-VCs, this study suggests the need to assess: subway station and bus stop area conditions in Santiago and Seoul, respectively; areas with high density of schools in Santiago; areas with greater concentrations of children in both cities; and collector roads in Seoul.

Keywords: child pedestrian-vehicle collisions, negative binomial regression model, spatial lag regression models, descriptive comparison, Santiago, Seoul

INTRODUCTION

Approximately 1.24 million people die and 50 million are injured annually in road traffic collisions worldwide, making them the ninth leading cause of global disability (WHO 2013a). According to the World Health Organization (2013a), approximately 50% of those killed globally are vulnerable road users (e.g., 22% pedestrians, 5% cyclists, and 23% motorcyclists). Children and young persons are especially susceptible; those under the age of 25 represent more than 30% of traffic deaths and injuries. Road traffic crashes are the leading cause of death among 10–19 year olds and will be the main cause of death in children under the age of 18 by 2030 (Peden 2009; WHO 2013b).

Collision causes and outcomes (e.g., deaths, injury severity) vary widely depending upon traffic engineering, driver training, culture, law enforcement, emergency response, health care capabilities, etc. Per capita-based crash indicators measure overall risks, comparable to other causes of death or injury (e.g., disease), while per vehicle-kilometer (or person-kilometer) indicators measure relative transport system risk, with per vehicle measures often used as a proxy, due to data availability (IRTAD, 2012). . Using cross-sectional data from 156 countries on income, population and traffic fatalities, Kopits and Cropper (2003) find support for the idea of a Kuznets curve (Stern, 2004) for overall traffic risk, with fatalities per capita increasing up to an income of approximately $8,600 per capita (International 1985$) and then declining with additional income increases. They find a similar result for the case of number of fatalities per 100,000 vehicles (Kopits and Cropper 2003). Pedestrians account for an average of 45% of road traffic fatalities in low and middle income countries, whereas in high income countries this value corresponds to 18% (Naci et al. 2009; Chandran et al. 2012).

Various studies compare traffic safety between different places, employing a variety of techniques (Amoros et al. 2003; Elvik and Mysen 1999; Hijar et al. 2000; Nantulya and Reich 2003; Ozkan et al. 2006; Soderlund and Zwi 1995; Treurniet et al. 2004; Williamson 2001). To our knowledge, however, no research has attempted a city-level comparative assessment of child pedestrian-vehicle collisions (P-VCs) and injury outcomes using statistics and spatial models. School-age children are particularly at risk in urban areas since walking is an essential form of healthy and liberating mobility. The risks to children can be exacerbated as urban land use and mobility systems become more motorized (Desapriya et al. 2010). We explore these risks in two cities on two continents, in distinct cultures, and at distinct points on the presumed collision risk Kuznets curve (due to their income differences): Santiago, Chile and Seoul, South Korea. First, we compare the situations using descriptive statistics of child P-VCs and associated injuries; subsequently, we specify various regression models to assess the similarities in relationships between child P-VCs and various attributes of urban environments.

Contexts and Questions

Santiago and Seoul are the capitals and largest cities of two dynamic nations. The Republic of Korea (hereafter South Korea), long an Asian economic success story, entered the OECD in 1996 and ranks 12th on the UN's Human Development Index (HDI), after Canada (UNDP, 2014). Chile, one of Latin America's most dynamic economies over the past 20+ years, entered the OECD in 2010 and ranks 40th on the HDI, behind Poland (UNDP, 2014). Both have modest population growth rates (<1%) and highly urbanized populations (World Bank, 2013). South Korea has about twice the per capita income, with both countries' economies growing at roughly equal rates per capita in recent years. South Korea has a more manufacturing-, technology-, and trade-oriented economy with lower unemployment, and higher levels of education and health expenditures. Consistent with their relative stages of economic development, South Korea emits more CO2 than, and has twice the motorization rate of, Chile, but Chile's per capita CO2 emissions and transport CO2 emissions are growing more rapidly (World Bank, 2013).

Chile and South Korea report yearly traffic collision data including injuries and fatalities by age, vehicle, and road use to the International Road Traffic and Accident Database (IRTAD), which was established by the OECD Road Transportation Research Program, and is now being managed by the ongoing working group of the International Transport Forum. Chile first provided their statistics in the 2014 IRTAD Annual Report. Over the past decade, both countries experienced declines in traffic fatalities, overall risk, transport system risk, and pedestrian deaths, consistent with a "Kuznets" theory for traffic collisions. The number of road fatalities per 100,000 inhabitants in 2012 was approximately 11 for both Chile and South Korea (IRTAD 2014). The percentage of pedestrian traffic deaths in both countries remained almost the same, about 38% in the period 2000-2010. Regarding transport system risk, South Korea, with higher motorization rates, has approximately half that of Chile. In both countries, the total youth (under 18 years old) share of pedestrian traffic deaths has declined by approximately 4% between 2000 and 2010 (CONASET 2013; IRTAD 2012).

As of 2011, South Korea has a fully funded strategic traffic safety training program (WHO, 2013a). The South Korean national government and the Seoul Metropolitan government have recently worked to improve pedestrian conditions, implementing new sidewalks, pedestrian-dedicated streets, and "pedestrian-friendly" districts. Targeting children's safety, the city designated zones around primary, middle, and high schools, encouraging the implementation of a variety of traffic calming measures. However, the quality of the pedestrian environment in Seoul still varies. In 2014, the Chilean National Commission of Traffic Safety (CONASET) developed a national plan focused on traffic safety education and information dissemination, particularly at schools. The short-term goal of this plan is to train school teachers about road safety and incorporate this topic in school curricula. This plan also includes campaigns to raise awareness and educate the general public.

Both capitals have similar areas, about 700 km^2 in Santiago and 600 km^2 in Seoul, but differ considerably in their land use and transportation systems. Seoul had almost double Santiago's population in 2010 (10.3 million versus 5.6 million) resulting in respective gross densities of 160 versus 72 persons per hectare, consistent with the general trend of Asian cities being denser than cities in Latin America. Santiago has approximately 16,000 km of roadways and a road density of 20 km/km^2, while Seoul's' corresponding figures are 8,666 km and 14.31 km/km^2. Seoul exhibits a variety of building types, street and land use patterns, and well-developed transportation systems. However, much of Seoul's urban transport and infrastructure design tends to be automobile-oriented, with wide major roads tending to be less pedestrian-friendly and neighborhood streets often lacking sidewalks. Santiago, historically monocentric with a dense urban core of commercial, office, education and health care, has undergone rapid suburban expansion of shopping, residential and office uses in the past 30 years (Zegras and Hannan, 2012). Santiago´s transportation system (known as Transantiago) has steadily been improved since its “big bang” implementation in 2007, with expansions and improvements ongoing (Muñoz and de Grange, 2010). While sidewalk provision is ubiquitous, major roadway infrastructures are highly automobile-oriented creating relatively inhospitable pedestrian conditions (e.g., crossings) near large arterials.

For these two cities, we first aim to determine if and how the overall magnitudes and relative risks of childhood P-VCs differ seasonally, temporally, spatially, and by gender. We then study in detail within and between the cities, examining spatial factors related to childhood P-VC risk for differing degrees of P-VC severity and two age groups (younger: 5 - 12, and older: 13 – 18 years old).

METHODS

Data Sources

We examined pedestrian crashes in 2010-2011 involving school-age children between 5 to 18 years-old. Santiago’s data come from the Chilean police’s statistical information system (Sistema de Información Estadística de Carabineros de Chile, SIEC 2) through CONASET, which maintains a database of all reported road traffic collisions. For Seoul, the Traffic Accident Analysis System maintains data collected by police at the incident scene, with inputs from car insurance companies and mutual aid associations. For Santiago, 975 child P-VCs were obtained for the studied period, of which 904 (92.7%) were successfully geocoded in GIS. For Seoul, the dataset included 3,532 child P-VCs, of which 3,505 (99.2%) were successfully geocoded (See Figure 1).

South Korea reports road fatalities immediately after a traffic incident or within 30 days as a result of an incident, whereas Chile informs deaths that occur immediately after an incident and up to 24 hours afterwards, resulting in estimated underreporting of 500 fatalities annually (CONASET 2012). Similar to Mexico’s reported underestimation of road traffic mortalities (Hijar et al. 2012), Chile also likely undercounts traffic-related deaths and injuries due to inconsistencies between police and hospital records. To represent land use characteristics in the zones of analysis in Santiago, we use data from the National Statistics Institute (INE), and a spatial dataset from the Chilean police. Seoul’s land use and other spatial data come from the Seoul Metropolitan Government.

Regression Models

Traffic crashes represent discrete, random, non-negative, and generally sporadic events (Miaou and Lum, 1993). These tend to be modeled in two different basic ways, each of which has its strengths and weaknesses. Incident-focused analyses take a disaggregate perspective, primarily focus on severity; that is, given the incident, how severely injured are those involved? Severity methods normally model an ordinal outcome, the degree of injury severity (e.g., Savolainen, et al., 2011). Such a focus has the clear benefit of being able to include a wide range of incident-specific factors of potential relevance such as weather conditions, time of day, infrastructure conditions, participant characteristics (e.g., age, income, education, gender, trip purpose), etc. A shortcoming of the incident-based approach comes from its inability to easily capture relatively safe places. If a specific place – e.g., zone in a city – has no incidents, its characteristics are excluded from the analysis, yet these exact characteristics are of interest because they are associated with lower levels of traffic risk. Aggregation offers an alternative approach, whereby incidents are aggregated into zones as the unit of analysis (e.g., Siddiqui et al, 2012). Such models have the strength of not excluding from the analysis places that are incident free, but with the loss of incident-specific details of relevance. We take an aggregate approach in this paper.

In aggregate models, crashes are often modeled as counts, such as with Poisson or Negative Binomial (NB) models. Prior research suggests NB models tend to be more appropriate for traffic collision data (Quddus, 2008). The appropriateness of NB versus Poisson for a particular dataset can be assessed in model estimation. Our results below confirm that NB is better for the child P-VC cases in both cities. Although in the case of fatal accidents, we estimate a binary probit, as no zone has more than one fatal P-VC recorded during the time period covered by our data. While the NB model does control for unobserved heterogeneity due to omitted variables (Quddus, 2008), it does not account for potential spatial dependencies which can violate regression assumptions.

Consider the traditional Ordinary Least Squares (OLS) model in Eq. 1.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_n X_n + \varepsilon \tag{1}$$

Where *Y* is the dependent variable, X_i are the independent variables; B_i are the regression coefficients representing the relationship between the dependent and independent variables; and ε represents random error.

Models of spatial phenomena, where variables are related to each other based on their spatial locations, may violate the assumption of independence among the error terms. Two basic problems may exist: i) spatial lag, whereby, for example, a poorly maintained house may negatively influence the value of neighboring houses; and ii) spatial error, whereby, for example, the measurement for a particular variable, such as crime rates, is a function of the local characteristics but also of omitted or unmeasured variables at neighboring locations (Baller et al. 2001).

A Spatial Lag (SL) model assumes that the dependent variable in location *i* is influenced by the values of the dependent and independent variables in the surrounding locations *j*, and a Spatial Error (SE) model allows the correlation of error terms across different spatial units (Vandenbulcke-Plasschaert 2011). Adapting Eq. (1), a SL model is represented as in Eq. 2.

$$Y = \rho W_y + X\beta + \varepsilon \tag{2}$$

Where ρ is the spatial lag factor and W_y is the weight matrix.

An SE model, can be represented as in Eq. 3.

$$Y = X\beta + \varepsilon \tag{3}$$

With $\varepsilon = \lambda W_\varepsilon + \xi$ (4)

Where the parameter λ is estimated to generate the autocorrelation level of the errors given the spatial weight matrix W_{ε}; and ξ is the vector of errors.

Bayesian methods have been developed and used to control for spatial dependencies in count-based crash analysis, but the results tend to be consistent with NB models (Aguero-Valverde and Jovanis, 2006; Quddus, 2008). In this paper, and following Quddus (2008), we estimate NB models and OLS-based SL/SE models. In the latter case, the dependent variable, the P-VC count was re-specified as an approximate exposure rate by dividing the P-VC count by zonal area (i.e., P-VC/km^2).

RESULTS

Descriptive Analysis

The cities have comparable child populations of 1,430,000 and 1,513,125, representing 22.7% and 15.4% of the total population for Santiago and Seoul, respectively. Seoul's lower share of children is consistent with South Korea's relatively older overall demographics. Considering the number of child pedestrians involved in collisions in the two cities (939 for Santiago and 3505 for Seoul), the overall crash risk rate for youth pedestrians in Seoul is up to 3.5 times higher: 66 per 100,000 children in Santiago versus 232 per 100,000 children in Seoul. Even accounting for likely differences in reporting levels, child pedestrians in Seoul evidently have a higher overall traffic risk, possibly due to higher exposure (e.g., more pedestrian activity).

Table 1 presents each city's disaggregate child pedestrian crash data by gender and severity of injury. South Korea classifies four injury types, whereas Chile has five types (unharmed, slightly injured, less seriously injured, seriously injured, and fatalities). For comparability, we combined Chile's "less seriously injured" (i.e., short term disability outcome) with the "seriously injured" (i.e., long term disability outcome) type. Overall, 96.8% and 93.5% of all child pedestrian crashes yielded some degree of physical injury in Santiago and Seoul, respectively. In both cities, the majority of child pedestrians involved in collisions were "slightly injured." Regarding the total number of child pedestrian injuries, more children were left unharmed in Seoul while more were killed in Santiago. Female children are less likely to be involved in P-VCs in both cities. This result is consistent with other research findings (Obeng 2011; Pfeffer et al. 2010; WHO 2013b) suggesting that males are more likely to be involved in road traffic crashes regardless of age. In both places older children (age 13 to 18) tend to be more involved in P-VCs, although Santiago has more older childhood P-VC victims (57% versus Seoul's 46%) while Seoul has more younger children (age 7 to 9) involved in P-VCs (24% versus Santiago's 16%). These tendencies may reflect cultural distinctions related to child independence. For instance, young children in Seoul may be exposed to higher traffic risk due to more independent mobility at a younger age relative to their peers in Santiago.

Childhood P-VCs in Santiago and Seoul present similar temporal patterns, with morning and evening peaks consistent with school travel. The only major break to this pattern is at 1 p.m. and 3 p.m., when the cities have different peaks due to school schedule differences for certain age groups (older children finish the daily school schedule at 1pm in Santiago and at 3pm in Seoul). Overall, the majority of the child P-VCs (58% in both cities) accumulate in the afternoon and evening. Weekdays account for most P-VCs in both cities, particularly Wednesdays and Fridays. These two days accounted for 34.3% (Santiago) and 31.6% (Seoul) of P-VCs during the period studied. In Santiago, most of the child pedestrian crashes (83%) occurred during the academic year (March to December), with a lower number recorded during the summer (i.e., January and February) and the July winter school break. Seoul's childhood P-VCs also reflect a summer break effect, with lower rates in July (8.1%) and August (6.5%). However, Seoul also has notably lower rates in January (5.5%) and February (6.0%), perhaps suggesting decreased amount of child outdoor street activities in Seoul's winter, which is colder and snowier than Santiago's. The two cities' weekly and monthly child P-VC proportions were all statistically different (at 95% confidence level) using a two-tailed test. Over 70% of Santiago's child P-VCs occurred at intersections, whereas in Seoul only 47.5% occurred at intersections and crossings. This may be due to at least two causes. First, according to Blazquez and Celis (2013), in Santiago, children cross roads surprisingly or carelessly, particularly when facing pedestrian red lights at intersections. Second, Korean children may obey traffic signals at intersections, but cross roads more often at midblock, yielding higher collision rates at these locations.

Model Variables

Table 2 presents the variables and descriptive statistics employed in our models. These variables were selected according to their impact on traffic collisions as found in multiple studies (Aguero-Valverde and Jovanis, 2006; Blazquez and Celis, 2013; Quddus, 2008; Sze and Wong, 2007) and their availability for both cities. We include bus and subway stations since access to these modes typically involves pedestrian movements and a large number of public transport users increases exposure of pedestrians to motor vehicle traffic (Hess et al., 2004). The land use diversity index measures the mix of land uses in a given zone. Mixed land use may increase walking activity and decrease motorization (e.g., Zegras, 2010). However, large number of pedestrians in a mixed-use area can be associated with higher traffic collision rates by increasing exposure (Moudon et al., 2011). We approximate land use mix as (Rajamani, 2003):

$$\text{Land Use Diversity Index } = 1 - \left\{ \frac{\left|\frac{r}{T} - \frac{1}{4}\right| + \left|\frac{c}{T} - \frac{1}{4}\right| + \left|\frac{i}{T} - \frac{1}{4}\right| + \left|\frac{g}{T} - \frac{1}{4}\right|}{\frac{3}{2}} \right\} \quad (5)$$

where, r = area in residential use (single and multifamily housing); c = area in commercial use; i = area in semi-industrial use; g = green area; and the total area, T = r + c + i + g. The resulting measure ranges from 0 for a zone with a single land use type to 1 for a zone with perfect mixing of land uses.

The percentages of arterial, collector, and local roads attempt to capture the effect of wide roadways, high traffic volumes, and high speed limits. For example, arterials tend be wider with higher traffic volumes and speeds than local roads. Hilliness is measured by dividing each district into 30x30m cells and averaging the cells' percent rise (change of height / change of distance) values. Hilliness can affect driving and walking behavior, thereby influencing P-VCs (Lee et al., 2013).

Figure 2 shows the density (i.e., number of child P-VCs per zone area) and rate (i.e., number of child P-VCs per zone child population) for Santiago and Seoul. Seoul's child P-VCs appear to be denser across a wider range than in Santiago, albeit with noticeably lower densities in the city center. Spatial patterns of P-VCs in both cities show numerous hot spots, implying the possible need for spatial models.

Exploratory analysis indicated high correlation between total population and child population. Thus, we excluded the former variable from the models. Similarly, the variables related to road density, intersection density, and percentage of local roads were also omitted from the models due to multicollinearity.

Model Estimation Results

We model three basic sets of outcomes: total P-VCs; P-VCs by severity (fatal, injured, no injuries) (See Table 3); and total P-VCs across younger (5-12) and older (13-18) children (See Table 4). The tables present the most parsimonious specifications for each model after numerous tests. For the spatial models, we present only the results of the SL models. For the Santiago case, no SE model was significant, possibly due to the larger and fewer spatial zones used in that city's models. Seoul's models showed evidence of both SL and SE; although the significance and directionality of the coefficient estimates do not vary across the spatial modeling approach.

The models show some variation in factors relating to different measures of P-VC severity across the cities (See Table 3). The age group-based models (See Table 4), while somewhat crudely dividing children into two age groups (within which much behavioral heterogeneity exists), provide some additional insights. We combine the discussion here. We do not discuss in detail fatalities, as few variables included in our models exhibit statistical significance – childhood fatalities in P-VCs are apparently rare enough in both cities to not be easily modeled for a given year.

For both cities, the results suggest an increase in all types of a zone's P-VCs as the zone's population of children increases. In Santiago, the danger appears to be primarily for younger children (See Table 4), possibly because younger children may stay closer to home (presuming a zone's population of children is a good proxy for residential concentration). Santiago also has some child P-VC risks at schools, with some evidence that P-VCs increase with the density of a zone's schools (although this seems primarily due to increase in non-serious P-VCs); here the problem appears primarily for older children. For Seoul, we observe the inverse with a modestly negative association between the density of a zone's schools and non-serious P-VCs. In Seoul, the residential-based risk is roughly consistent across the age groups, while school-dense zones have apparently low relative P-VC risk.

With respect to public transport access/egress, a somewhat mixed picture emerges. With bus stops in Santiago, the evidence is inconclusive as the spatial versus count models reveal contradictory evidence, including across age groups. For Seoul, the count models indicate a positive relationship between bus stops and total, serious, and non-serious P-VCs; the relationships are consistent across age groups. For subway stations, in Santiago significantly positive relationships appear between subway station densities and child P-VCs. This result seems to be a problem for older children, again evidence of increased mobility for older versus younger children in Santiago (significant in both NB and SL models) and indicative of problematic pedestrian safety treatments at subway stations in the city. For Seoul, modest evidence ($p = 0.08$ in NB model only) of a P-VC risk for older children emerges.

Regarding other zonal characteristics, land use mix in Seoul is negatively associated with child P-VCs, suggesting greater zonal land use mix might reduce motorized traffic and/or related dangers, across children age categories. For Seoul's street characteristics, a zone's share of arterial streets is associated with fewer total P-VCs and non-serious P-VCs, but this seems to be primarily for younger children. Interestingly, while little evidence emerges on the relationship between arterials and P-VC severity in Santiago, a negative effect is detected for younger groups, similar to the Seoul case. This may be due to lower levels of younger children's activities on arterials in both cities and/or arterial designs with physically segregated facilities. Regarding collector roads, in Seoul, their share consistently reveals a positive relationship across P-VC types (the collector's "effect" is double the arterial's) and age categories; this may be due to higher levels of childhood pedestrian activities and/or more pedestrian-vehicle conflicts on slower collector roads. In the Santiago case, a zone's share of collector roads is negatively associated with younger children P-VCs. Finally, a zone's "hilliness" (i.e., slope) tends to be negatively associated with P-VCs in both cities, particularly in the spatial models. These may be areas with less child pedestrian movements – for example, Santiago is relatively flat, except in the wealthier foothills, where children may be less-inclined to walk on suburban streets. Additional contemporaneous information, such as on children's actual local travel patterns, would ultimately be needed to better explain the model results.

CONCLUSION

The global traffic mortality and morbidity epidemic will likely continue to get worse before it gets better, as engineering, cultures, and institutions adapt to more motorized travel. We examined cities in two countries apparently improving their traffic safety conditions. Specifically, we studied P-VCs involving children in Santiago, Chile and Seoul, South Korea over the 2010-2011 period. The data suggest that children in Seoul have a higher risk of being involved in P-VCs than their counterparts in Santiago. This may be due to higher pedestrian activity levels, more dangerous traffic conditions or a combination of these and other factors. The different reporting levels in the two cities could be another important explanation for this difference, but its effect cannot be assessed at this point. In Seoul, however, a higher share of children escapes without injury than in Santiago, where more child P-VCs result in injuries and death. Younger pedestrians in Seoul constitute a greater proportion of crash victims than their counterparts in Santiago. Perhaps children in Seoul have more independence to venture into public spaces at an earlier age and/or these public spaces have higher traffic risk. This trend is reversed for older children in Santiago, where younger children may more likely be accompanied by an adult. In both cities, male children have a higher likelihood of being in P-VCs and P-VCs' temporal patterns are consistent with school schedules. More child P-VCs occur at intersections in Santiago, perhaps due to tendencies to disobey traffic signals. Seoul has more child P-VCs at mid-blocks; perhaps children there obey traffic signals at intersections, but make more midblock crossings. Further investigation into child pedestrian behavioral patterns when crossing the streets is clearly needed.

Our models have modest explanatory power, at least partly due to the difficulty in finding comparable explanatory variables to test across the two contexts. The resident population of children is positively associated with P-VCs in both cities, and school concentrations apparently increase P-VC risk among older children in Santiago. In terms of public transportation, bus stops are associated with higher P-VCs in Seoul, while subway stations relate with higher P-VCs among older children in Santiago. Zone-level land use mix was negatively related to child P-VCs in Seoul, but not in Santiago. Perhaps these locations have more congestion and slower traffic and/or generate more pedestrian traffic making drivers more cautious (Thompson et al., 2014). Street types play some role, with arterials associated with fewer P-VCs, especially for younger children in both cities, perhaps reflecting activity patterns and/or physical characteristics of these streets. A zone's share of collector roads is associated with increased P-VCs in Seoul, but fewer P-VCs in Santiago. Topography also plays an apparent role, hilliness associated with fewer P-VCs in both cities, possibly reflecting lower pedestrian activities in such zones. Differences in these model results for Santiago and Seoul warrant additional analysis as do the differences in results across model type (NB versus SL models).

This study has several limitations. First, consistent incident reporting is unlikely across the two contexts. We are aware of underreporting of crash fatalities in Chile due mainly to differences between police reports and hospital records. This underreporting may have led to biased results in our models by underestimating the likelihood of fatal or high severity P-VCs (Ye and Lord, 2011; Patil et al., 2012). The nature of this potential bias warrants further study. Second, the models' explanatory variables were those we found common for both cities; therefore, numerous potential factors remain outside of our analysis, such as: traffic risk exposure (volumes and speeds), pedestrian activity (trips, routes, volumes), zonal socioeconomic conditions, and road configurations and pedestrian facilities. Third, the count models used (negative binomial) could, in the future, be modified using Bayesian-based techniques to account for spatial effects (e.g., Quddus, 2008). More generally, using spatial zones as the units of analysis poses problems: the findings may be sensitive to the size and shape of the zones aggregating the data (i.e., the modifiable areal unit problem); and, richer information on the specific incident attributes (time of day, weather, age of persons, roadway geometries, etc.) cannot be used in the zonal aggregation approach. Future analysis could focus on incidents as the unit of analysis, which would allow for such specific attributes to be included. Value might also be gained by extending beyond pedestrian risks alone and/or comparing pedestrian risks for children with the other modes by which they travel in the city. Finally, a more complete picture of traffic safety would come with data over a longer time period.

This study offers a first comparative assessment of child P-VC risk in Santiago and Seoul. Additional work is needed to better understand the comparative traffic safety risks especially for children in rapidly motorizing urban settings. Child pedestrians are vulnerable road users that require targeted safety interventions and we have offered some initial indications of the similarity in vulnerabilities in two different cities.

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Table 1: Number and percentage of child pedestrians involved in P-VCs, by gender and type of injury in Santiago and Seoul

Type of Injury	Santiago						Seoul					
	Female		Male		Total		Female		Male		Total	
	n	%	n	%	n	%	n	%	n	%	n	%
Unharmed	10	1.1%	20	2.2%	30	3.3%	91	2.6%	138	3.9%	229	6.5%
Slightly Injured	265	29.3%	297	32.9%	562	62.2%	830	23.7%	1084	30.9%	1914	54.6%
Seriously Injured	115	12.7%	186	20.6%	301	33.3%	576	16.4%	769	21.9%	1345	38.4%
Fatalities	6	0.7%	5	0.6%	11	1.2%	8	0.2%	9	0.3%	17	0.5%
Total	396	43.8%	508	56.2%	904	100.0%	1505	42.9%	2000	57.1%	3505	100.0%

Table 2: Variables and Descriptive Statistics

Variables	Description	Santiago (n = 225)				Seoul (n = 424)			
		Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Dependent Variables									
Total Child P-VC*	Number of Child P-VC	4.02	3.53	0	18	8.27	5.24	0	34
Total Child Fatalities	Number of Fatal Child P-VC	0.05	0.22	0	1	0.04	0.20	0	1
Total Child Serious Injuries	Number of Serious Child P-VC	1.34	1.57	0	8	3.17	2.26	0	11
Total Child Slight Injuries	Number of Slight Child P-VC	2.63	2.51	0	13	5.05	3.77	0	29
Younger Child P-VC	Number of Younger Child (5-12) P-VC	1.73	1.89	0	10	4.44	3.16	0	16
Older Child P-VC	Number of Older Child (13-18) P-VC	2.28	2.33	0	11	3.82	3.20	0	23
Child P-VC Density	Child P-VC / km^2	1.63	1.50	0	6.75	8.41	5.92	0	33.86
Fatal Child P-VC Density	Fatal Child P-VC / km^2	0.02	0.13	0	1.74	0.03	0.19	0	1.49
Serious Child P-VC Density	Serious Child P-VC / km^2	0.52	0.66	0	4.32	3.21	2.67	0	12.68
Slight Child P-VC Density	Slight Child P-VC / km^2	1.08	1.16	0	6.45	5.16	4.21	0	28.88
Younger Child P-VC Density	Younger Child P-VC / km^2	0.68	0.75	0	3.39	4.56	3.73	0	22.54
Older Child P-VC Density	Older Child P-VC / km^2	0.95	1.08	0	5.25	3.85	3.44	0	22.91
Independent Variables									
Area	Area (Square Kilometer)	4.61	9.28	0.45	113.90	1.43	1.59	0.21	12.71
Child Population	Child Population	7285.7	5549.4	11	29580	3456.2	1667.3	50	11300
School	Number of Schools	10.08	8.14	0	52	2.51	1.83	0	11
Bus Stop	Number of Bus Stops	49.32	27.73	0	152	14.68	9.49	0	52
Subway	Number of Subway Stations	0.44	0.81	0	4	0.75	0.96	0	6
Land Use Mix	Land Use Diversity Index	0.38	0.18	0	0.79	0.21	0.17	0	0.71
Pct_Arterial	Percentage of Arterial Roads	10.12	7.74	0	44.41	41.45	25.69	0.28	100.00
Pct_Collector	Percentage of Collector Roads	10.69	7.45	0	35.43	15.46	16.95	0	53.58
Pct_Local	Percentage of Local Roads (Base)	79.19	10.45	44.02	100.00	43.09	37.26	0	99.18
Slope	% Rise	2.28	3.22	0.12	24.71	7.81	6.46	0.28	31.14

Note: *: Pedestrian-Vehicle Collisions

Variables	Description	Santiago (n = 225)				Seoul (n = 424)			
		Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Dependent Variables									
Total Child P-VC*	The Number of Child P-VC	4.02	3.53	0	18	8.27	5.24	0	34
Total Child Fatalities	The Number of Fatal Child P-VC	0.05	0.22	0	1	0.04	0.20	0	1
Total Child Serious Injuries	The Number of Serious Child P-VC	1.34	1.57	0	8	3.17	2.26	0	11
Total Child Slight Injuries	The Number of Slight Child P-VC	2.63	2.51	0	13	5.05	3.77	0	29
Younger Child P-VC	The Number of Younger Child (5-12) P-VC	1.73	1.89	0	10	4.44	3.16	0	16
Older Child P-VC	The Number of Older Child (13-18) P-VC	2.28	2.33	0	11	3.82	3.20	0	23
Child P-VC Density	Child P-VC / km^2	1.63	1.50	0	6.75	8.41	5.92	0	33.86
Fatal Child P-VC Density	Fatal Child P-VC / km^2	0.02	0.13	0	1.74	0.03	0.19	0	1.49
Serious Child P-VC Density	Serious Child P-VC / km^2	0.52	0.66	0	4.32	3.21	2.67	0	12.68
Slight Child P-VC Density	Slight Child P-VC / km^2	1.08	1.16	0	6.45	5.16	4.21	0	28.88
Younger Child P-VC Density	Younger Child P-VC / km^2	0.68	0.75	0	3.39	4.56	3.73	0	22.54
Older Child P-VC Density	Older Child P-VC / km^2	0.95	1.08	0	5.25	3.85	3.44	0	22.91
Independent Variables									
Area	Area (Square Kilometer)	4.61	9.28	0.45	113.90	1.43	1.59	0.21	12.71
Child Population	Child Population	7285.7	5549.4	11	29580	3456.2	1667.3	50	11300
School	Number of Schools	10.08	8.14	0	52	2.51	1.83	0	11
Bus Stop	Number of Bus Stops	49.32	27.73	0	152	14.68	9.49	0	52
Subway	Number of Subway Stations	0.44	0.81	0	4	0.75	0.96	0	6
Land Use Mix	Land Use Diversity Index	0.38	0.18	0	0.79	0.21	0.17	0	0.71
Pct_Arterial	Percentage of Arterial Roads	10.12	7.74	0	44.41	41.45	25.69	0.28	100.00
Pct_Collector	Percentage of Collector Roads	10.69	7.45	0	35.43	15.46	16.95	0	53.58
Pct_Local	Percentage of Local Roads (Base)	79.19	10.45	44.02	100.00	43.09	37.26	0	99.18
Slope	% Rise	2.28	3.22	0.12	24.71	7.81	6.46	0.28	31.14

Table 3: Results of NB, Probit (P) and SL Models of Child P-VC by the Level of Severity

Variables	**Santiago (n=225)**								**Seoul (n=424)**							
	T_{NB} β (SE)	**T_{SL}** β (SE)	**F_{P}** β (SE)	**F_{SL}** β (SE)	**I_{NB}** β (SE)	**I_{SL}** β (SE)	**NI_{NB}** B (SE)	**NI_{SL}** β (SE)	**T_{NB}** β (SE)	**T_{SL}** β (SE)	**F_{P}** β (SE)	**F_{SL}** β (SE)	**I_{NB}** β (SE)	**I_{SL}** β (SE)	**NI_{NB}** B (SE)	**NI_{SL}** β (SE)
Ln(Area)	-0.144^ (0.082)		0.522* (0.23)								0.243 (0.185)					
Ln(Child Pop.)	0.313× (0.085)	0.15 (0.13)		-0.02 (0.01)	0.582× (0.141)	0.13* (0.06)	0.198* (0.094)		0.548× (0.047)	1.805× (0.413)	0.642* (0.292)	0.028* (0.015)	0.478× (0.066)	0.746× (0.202)	0.566× (0.058)	1.177× (0.304)
School	0.015* (0.007)	0.02 (0.01)		-0.00 (0.00)	0.004 (0.01)	-0.002 (0.01)	0.021× (0.008)	0.018^ (0.011)		-0.260^ (0.143)			0.024 (0.02)	-0.108 (0.072)		-0.173^ (0.106)
Bus Stop	0.009× (0.003)	-0.01× (0.004)		0.00 (0.00)	0.004 (0.004)	-0.003 (0.002)	0.006* (0.003)	-0.008** (0.003)	0.018× (0.003)				0.013× (0.004)		0.020× (0.003)	
Subway	0.106^ (0.063)	0.30** (0.12)		0.01 (0.01)	0.163^ (0.086)	0.13* (0.05)	0.091 (0.067)	0.215* (0.093)	0.034 (0.029)	0.296 (0.252			0.052 (0.034)			-0.223 (0.186)
Land Use Mix			-1.172 (0.926)	-0.02 (0.05)			0.091 (0.067)	-0.441 (0.404)	-0.330* (0.151)	-8.731× (1.424)		-0.066 (0.055)	-0.265 (0.191)	-4.052× (0.711)	-0.385* (0.183)	-5.082× (1.047)
% Arterial		-0.02 (0.01)	0.032 (0.021)	0.00 (0.00)		-0.003 (0.01)		-0.019^ (0.009)	-0.003× (0.001)	-0.031× (0.011)		-0.0004 (0.0004)	-0.001 (0.001)	-0.008 (0.005)	-0.004× (0.001)	-0.023× (0.008)
% Collector		-0.02 (0.01)	0.138 (0.017)	0.00 (0.00)		-0.01* (0.005)		-0.014 (0.009)	0.006× (0.002)	0.064× (0.016)		0.0004 (0.0006)	0.006× (0.002)	0.023× (0.008)	0.007× (0.002)	0.042× (0.012)
Slope		-0.10× (0.02)	-0.805* (0.346)	-0.00 (0.00)		-0.03^ (0.01)	-0.043* (0.021)	-0.087× (0.023)	-0.004 (0.004)	-0.201× (0.038)	-0.023 (0.020)	-0.002 (0.001)	-0.005 (0.005)	-0.081× (0.019)		-0.121× (0.028)
Constant	-1. 93× (0.67)	0.67 (1.06)	-1.313* (0.645)	0.14 (0.11)	-5.20× (1.12)	-0.34 (0.51)	-1.17 (0.799)	-1.663× (0.285)	-2.526× (0.386)	-4.66 (3.228)	-6.88× (2.421)	-0.153 (0.120)	-2.65× (0.528)	-1.531 (1.567)	-3.161× (0.465)	-3.435 (2.385)
Alpha/ Rho (*ρ*)	0.263× (0.054)	0.325* (0.078)	n.a.	-0.023 (0.098)	0.30× (0.114)	0.103 (0.092)	0.240× (0.065)	0.245× (0.083)	0.122× (0.017)	0.389× (0.059)	n.a.	-0.051 (0.082)	0.070× (0.028)	0.160* (0.071)	0.167× (0.026)	0.406× (0.059)
R-Sq.	0.081	0.252	0.171	0.029	0.081	0.103	0.075	0.194	0.079	0.363	0.079	0.017	0.064	0.20	0.069	0.313

Notes: T: total; F: fatal; I: injured; NI: no injury; subscripts denote model type: negative binomial [NB], probit [P], spatial lag [SL]. Alpha is dispersion parameter in NB models; Rho is lag coefficient in SL models. ^: $p \leq .10$; *: $p \leq .05$; ×: $p \leq .01$

Table 4: Results of NB and SL Models of Child P-VC by Age Category

Variables	Santiago (n=225)				Seoul (n=424)			
	Y_{NB} β (SE)	**Y_{SL}** β (SE)	**O_{NB}** B (SE)	**O_{SL}** β (SE)	**Y_{NB}** β (SE)	**Y_{SL}** β (SE)	**O_{NB}** B (SE)	**O_{SL}** β (SE)
Ln(Area)	-0.123 (0.105)							
Ln(Child Pop.)	0.637× (0.142)	0.149* (0.063)	0.088 (0.098)		0.647× (0.065)	1.084× (0.250)	0.442× (0.064)	0.789× (0.261)
School			0.025× (0.009)	0.020* (0.009)	0.025 (0.018)			-0.186* (0.094)
Bus Stop	0.006^ (0.004)	-0.004* (0.002)	0.007* (0.003)	-0.007× (0.003)	0.012× (0.003)		0.020× (0.004)	
Subway	0.082 (0.077)	0.074 (0.056)	0.163* (0.074)	0.220× (0.081)		-0.260 (0.165)	0.070^ (0.039)	
Land Use Mix	0.440 (0.400)		-0.514 (0.378)	-0.490 (0.352)	-0.443× (0.205)	-5.898× (0.920)	-0.248 (0.214)	-3.581× (0.919)
% Arterial	-0.024* (0.011)	-0.018× (0.006)			-0.004× (0.001)	-0.024× (0.007)	-0.002 (0.002)	-0.009 (0.007)
% Collector	-0.018^ (0.010)	-0.017× (0.006)			0.008× (0.002)	0.050× (0.011)	0.005* (0.002)	0.018^ (0.011)
Slope		-0.042× (0.014)	-0.40^ (0.023)	-0.063× (0.020)		-0.100× (0.024)	-0.009 (0.006)	-0.106× (0.024)
Constant	-5.101× (1.253)	-0.175 (0.522)	-0.418 (0.829)	0.978× (0.215)	-3.90× (0.509)	-3.032 (2.005)	-2.485× (0.522)	-1.40 (2.037)
Alpha/ Rho (*ρ*)	0.159× (0.072)	0.301× (0.079)	0.338× (0.083)	0.372× (0.076)	0.107× (0.023)	0.307× (0.063)	0.232× (0.035)	0.279× (0.068)
R-Sq.	0.118	0.253	0.064	0.250	0. 084	0. 307	0.049	0.183

Note: Y: 5-12 years old; O: 13-18 years old; subscripts denote model type (negative binomial [NB], spatial lag [SL]. Alpha is dispersion parameter in NB models; Rho is lag coefficient in SL models. ^: p ≤ .10; *: p ≤ .05; ×: p ≤ .01

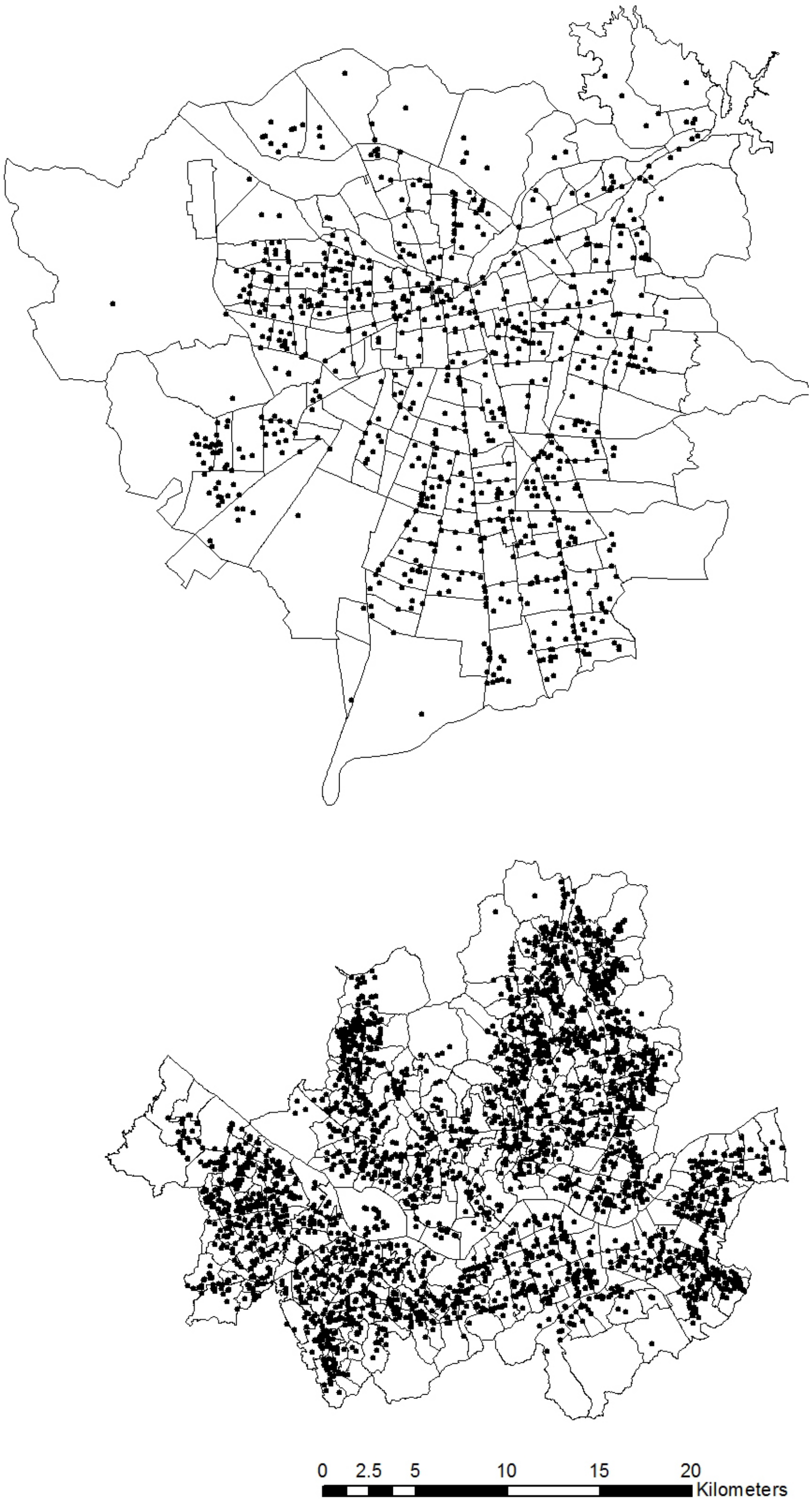

Figure 1: Child P-VCs in Santiago (top) and in Seoul (bottom) between 2010 and 2011

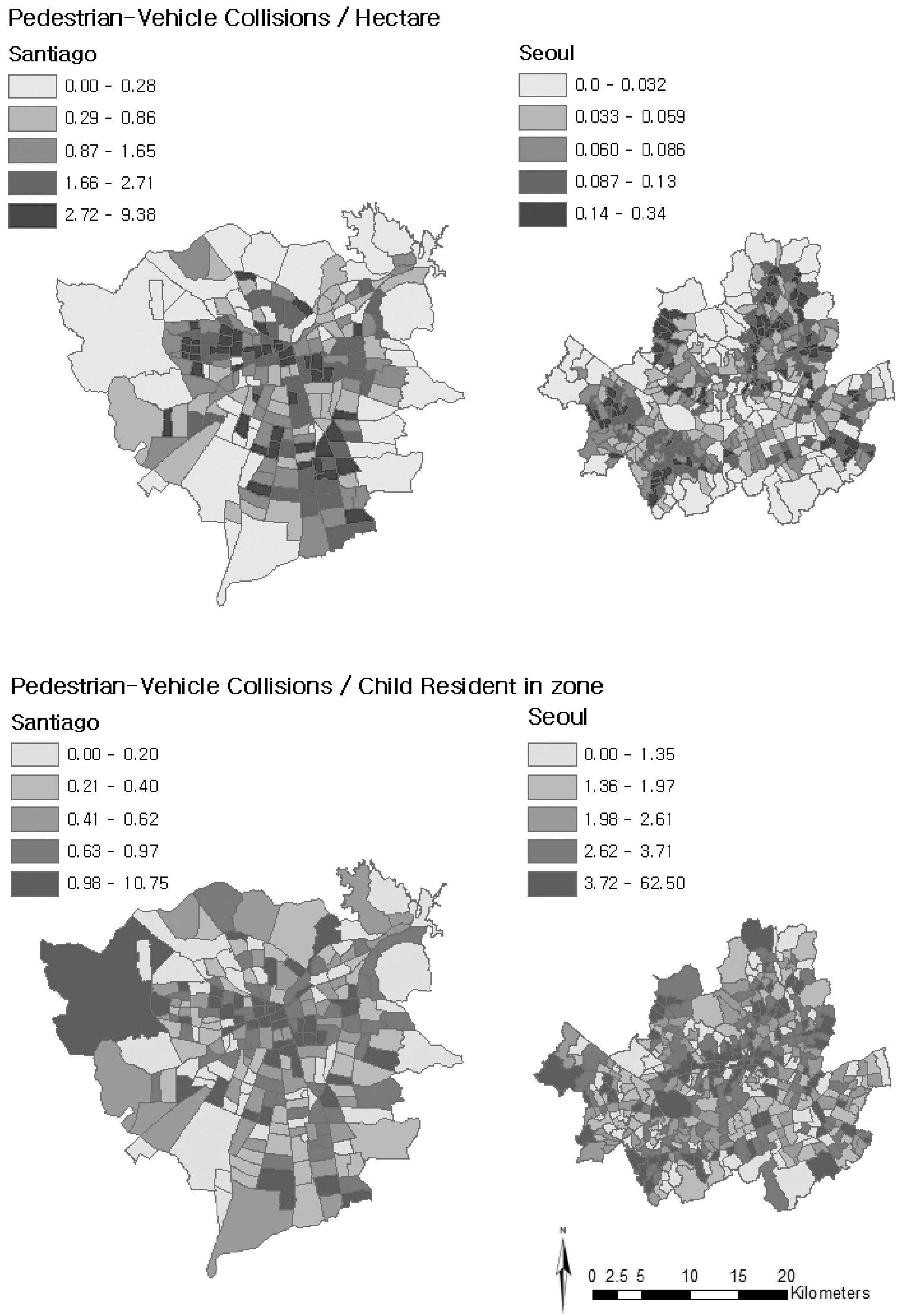

Figure 2: Child P-VC Density (top) and Rate (bottom) for Santiago and Seoul