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Original Road Safety Research

Using Big Data for Improving Speed Enforcement and Road Safety Engineering Measures: An Application in Bogota, Colombia

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Key Findings

- Data show that speeding is a strong factor in the severity of traffic crashes and fatalities;
- 35% of Bogotá's reported traffic fatalities are located on 12% of the city's arterial roads;
- If speed enforcement is applied in the selected corridors, an estimated 78% of fatalities in these locations would be avoided;
- Agglomerating geocoded speed data and casualty data can help target speed enforcement to achieve the greatest safety impact with limited resources;
- The corridors selected for speed management registered 10.2% of vehicles' speeding.

Abstract

Enforcing speed limits is an effective measure to reduce traffic deaths and serious injuries as part of a comprehensive road safety strategy. In this paper, we explore the integration of geocoded traffic crash data and traffic speed sensors based on Wi-Fi/Bluetooth technology, to identify critical arterial road segments in Bogotá, Colombia. Big-data amalgamation and analysis allow a more effective focus in places with a high concentration of traffic crash victims and a high percentage of speeding traffic. This type of analysis helps inform the assignment of scarce traffic police resources to maximize impact. It also guides the effective location of speed cameras and traffic calming measures. Strict speed enforcement on the 17 arterial road segments identified in Bogotá may result in a 4% decline in the total number of fatalities per year citywide. As the current target for Bogota is a reduction of fatalities by 3.5% per year, these measures will meet and surpass this goal. Detailed speed data also show the hours and days of the week where speeding represents a higher risk, helping target enforcement. The proposed methodology can be replicated in other places and has the potential to be improved as additional data become available.

Keywords

Speed controls, big data, road safety, speed management, speed enforcement, traffic crashes, traffic crash victims

Introduction

Road crashes claim 1.25 million lives annually, with the highest road traffic fatality rates in low-income countries (World Health Organization, 2015). Speed is recognized as a major risk factor, especially for pedestrians (Organization for Economic Cooperation and Development, 2006; Rosén & Sander, 2009). Reducing average vehicle speed results in large reductions of traffic deaths (Greibe, 2005). Speeds are best reduced through a combination of infrastructure, legislation and enforcement measures (Organization for Economic Cooperation and Development, 2006). In low- and middle-income countries, traffic regulations are the most common measure for road traffic injury prevention, which has the best outcomes when combined with strong enforcement (Staton, C. et al., 2016).

Resources for enforcement are often limited, particularly in developing countries. Cities have a small traffic police force (Global Road Safety Partnership, 2008), and speed enforcement can be demanding (Sisiopiku & Patel, 1999). Camera enforcement may help increase effectiveness (Mountain, Hirst & Maher, 2005; Wilson, Willis, Hendrikz, Le Brocque, & Bellamy, 2010; Job & Sakashita, 2016), but implementation requires sizeable investment and faces strong opposition from car drivers. Infrastructure measures can be more effective than speed cameras in some cases (Mountain et al., 2005) but it may not be appropriate to use, for example, speed bumps in main roads.

In this context, deploying scarce police units for speed enforcement is important for local transport authorities to achieve maximum impact. Traditional approaches are based on geolocation of traffic fatalities and injuries and using heat maps to identify the segments of the road network with the greatest concentration of casualties (Bell & Schuurman, 2010). Nevertheless, heat maps may not correctly show the most hazardous segments for speed, as they depend on police records that often attribute "human error" as the probable crash cause or do not include a probable cause at all. It is also difficult to determine which of the vehicles involved in a collision were speeding (Doecke & Kloeden, 2011).

The rapid growth of information technologies provides new opportunities for complementing geocoded crash data. Big data has begun to be used to inform sustainable mobility planning (Semanjski, Bellens, Sidharta Gautama & Witlox, 2016), real time traffic operations and safety monitoring (Shi & Abdel-Aty, 2015). Application of such data is currently concentrated in industrialized countries, but there is a wide potential to leapfrog in developing countries.

This paper presents a case study of the applied combination of big data and geocoded traffic crash data to document opportunities and results in a developing city context. The first section presents basic information on road safety in Bogotá, and describes the data used in this study. The second section describes the methodology followed. The third section presents the results and analysis. The final section presents the conclusions, recommendations and suggestions for further research.

The aim of this study is to identify priority corridors for speed management in Bogotá based on speed and road safety data. It also aims to prove the methodology and the importance of combining and using big data to improve the impact of road safety measures.

Road safety in Bogotá and data used

In 2016, Bogotá had 7,980,001 inhabitants, 459,761 motorcycles and 1,120,279 automobiles (Bogotá Cómo Vamos, 2017). While motorization is relative low (198 motor vehicles per 1,000 people), and most trips are by public transport (44%) and walking (31%), congestion is a big problem. Average travel speeds in 2016 were 22 km/h for cars and taxis, 17 km/h for conventional buses, and 26 km/h for rapid transit buses (Bogotá Cómo Vamos, 2017). The number of traffic fatalities has oscillated between 500 and 600 over the last decade with no clear trend, while the average travel speeds have been declining (Camara de Comercio & Universidad de los Andes, 2017). 582 deaths and 15,008 road traffic injuries were registered in the city in 2016 (Bogotá Cómo Vamos, 2017). Most registered deaths in 2016 were pedestrians (48%), followed by motorcycle users (35%) and bicycle users (12%).

Bogotá has made excellent progress with geocoded traffic crash data. For this study, we used data from 2011-2015 provided by the local traffic authority (Secretaria Distrital de Movilidad). The database includes the geolocation for 38,350 casualties (1,645 fatalities and 36,705 injuries).

In 2016, the city launched a traffic control centre with state-of-the-art traffic sensors, including 350 Wi-Fi/Bluetooth devices capable of detecting individual speeds for road segments and full corridors, 160 automatic traffic counting devices, 12 automatic bicycle counting devices, and CCTV Cameras to monitor 100 intersections (Secretaria Distrital de Movilidad, 2015). This case study used the data of the first week of September 2016, which is considered representative as a typical week, as there are no vacation periods or holidays during this time of year.

Speed data for Bogotá is collected by a Wi-Fi/Bluetooth device that captures mobile phone signals as they cross intersections. Most signals come from smart phones with open Wi-Fi or Bluetooth technology. When the same mobile phone is captured by another device in another intersection, the time passed between a first and a second intersection is recorded. The time recorded is assigned to the segment between the two devices that captured the cell phone. Segment lengths can vary from 100 meters to 4,000 meters. Since the distance between the devices is constant, with this information it is possible to automatically calculate the speed of the cell phone movement in the segment. Although the speed data is generated by the mobile phones, not vehicles, the speed captured corresponds to the average speed of each vehicle in each segment. The system also registers the time and date of the captured phone and the identification number of the segment where it was captured. Data is anonymized and impossible to track back.

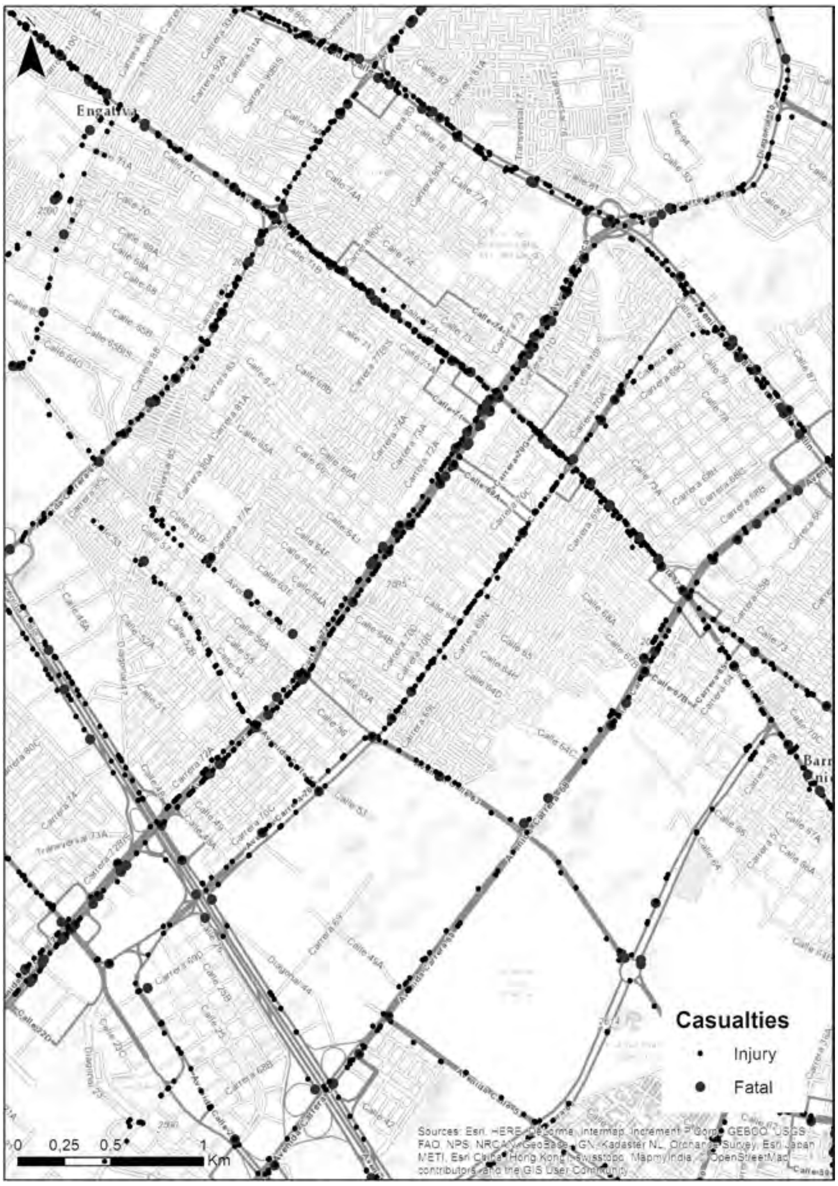

Figure 1. Example of Geolocation of Casualties after Data Processing. Source: Prepared by the Authors based on data provided by Secretaria Distrital de Movilidad, 2017

The speed database for Bogotá has close to 1.46 million records, and collects around 300 samples of speed per hour per road segment every week, although not all vehicles are tracked. The minimum speed registered is 4 km/h in order to exclude walking trips, and speed is not differentiated by type of vehicle; hence the sample contains speed measures for: bicyclists, motorcycle users, car and truck drivers and passengers, and public transport passengers. The lack of differentiation between vehicle types could potentially cause a bias, because most of the recorded speeds in an arterial road could be from public transport users, especially when BRT corridors are present. Nevertheless, this data is likely more reliable than the methodology used in the past to sample travel speeds, which was based on a vehicle traveling three to four times along city corridors. In contrast, the sample collected by the Wi-Fi/Bluetooth devices generates more than one million trip records per week.

The speed limit considered for the analysis is 60 km/h in all segments. This is because the highest posted speed limit in the city is 60 km/hour, and as a result drivers believe that the speed limit in all arterial roads is 60 km/h. In fact, the current law states that the speed limit in Bogota is 80 km/h unless posted differently (Congreso de la República de Colombia, 2002). Nevertheless, traffic police carry out speed control based on a 60 km/hour limit.

Methods

The first step of the process was to categorize arterial road segments according to the number of fatalities per year. This required data processing to geolocate specific road segments. Only the data close to (less than 50 meters away), or on, arterial roads was considered for the analysis (Figure 1). During the processing some errors in geocoding,

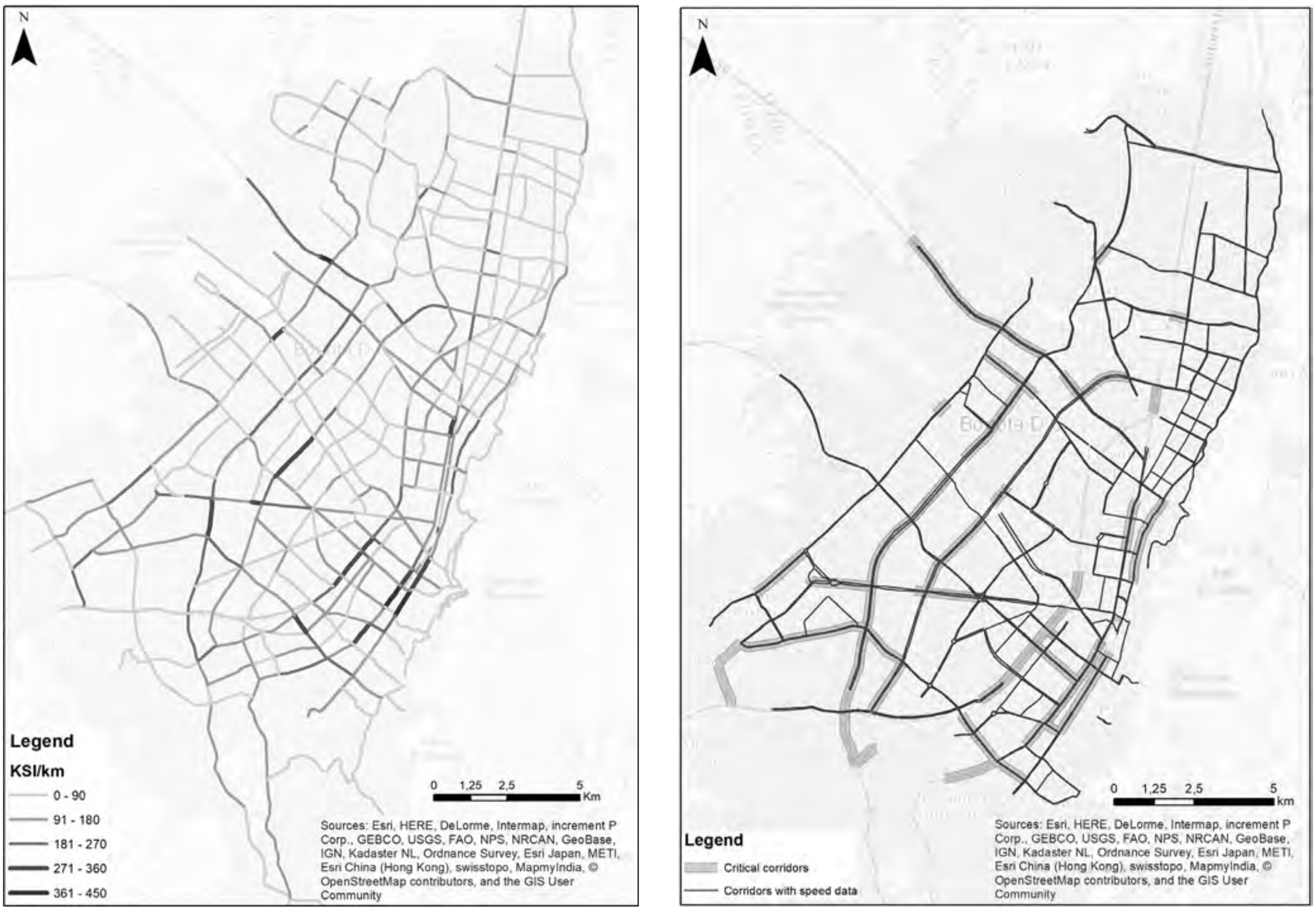

Figure 2. Casualties (KSI) per Km and Selected Critical Links (>35 casualties/km/year). Source: Prepared by the Authors based on data provided by Secretaria Distrital de Movilidad, 2017

were identified, both in the police report format and in manual data entry. As a result, the data to has an estimated error distance of 50 meters. However, the data was still sufficient to categorize road segments thanks to the high number of victim records available (38,350) and relative good precision. The number of casualties per kilometre was calculated, and arterial segments with more than 35 casualties per kilometre per year and with high speeds identified were selected as critical (Figure 2). As the Wi-Fi/Bluetooth detectors are attached to traffic lights, highways without signalized intersections were not included in the analysis.

Speed distribution was then analysed for the critical segments. The proportion of vehicles travelling at more than 60 km/h in each of the critical corridors was calculated. This speed was used as a point of reference since it is the highest speed limit posted on arterial roads. Seventeen segments were identified as having more than 35 casualties per year and more than 5% of the traffic exceeding 60 km/h. These were recommended for targeted speed enforcement (Figure 3).

Finally, the fatality reduction potential was estimated using a formula developed through meta-analysis of speed control strategies in Norway (Greibe, 2005):

$$F_1 = F_0 \left(\frac{V_1}{V_0}\right)^{3.6} \qquad (1)$$

where:

- F_1 is the number of fatalities after the speed control measure
- F_0 is the number of fatalities before the speed control measure (32 fatalities per year in all segments)
- V_0 is the average speed before the speed control measure (55 km/h)
- V_1 is the average speed after the speed control measure (35 km/h). The after speed was estimated assuming all vehicles comply with the speed limit of 60 km/h. The distribution after was estimated as if vehicles speeding were proportionally distributed between 0 and 60 km/h after speed management implementation, according to the proportion of vehicles travelling in that range before
- 3.6 is a coefficient estimated from multiple before and after studies for fatalities. The coefficient for estimating the change in injuries is 2.

According to this formula, if speed control is applied in the 17 segments, assuming a 100% compliance with the speed

Figure 3. Segments combining more than 35 casualties/year and 5% of the traffic exceeding 60 km/hour. Source: Prepared by the Authors based on data provided by Secretaria Distrital de Movilidad, 2017

limit, an estimated 78% of fatalities in these locations would be avoided (the number of fatalities would decrease from 32 per year to 7) and the amount of serious injuries would decrease by 60% (the number of traffic related injuries would decrease from 732 per year to 292). Such a reduction in fatalities would generate a reduction of the total annual fatalities in the city by 4% (25 fatalities). As the city has established a formal goal to reduce fatalities by 3.5% per year as in the District Road Safety Plan 2017-2026 (Alcaldía Mayor de Bogotá, 2016), applying strict speed controls on the selected segments would be sufficient to achieve the overall city goal. This finding shows the potential benefit of combining the two data sources (geocoded crash data and vehicle speeds) for the selection of segments for speed enforcement.

Analysis

The data analysis presented in this paper identified the corridors with the highest potential to reduce the number of traffic collisions. The analysis identified corridors which had both a high number of annual casualties (over 35) and a high proportion of vehicles speeding (over 5%) to be targeted for speed enforcement, (Figure 4).

On average, 35% of Bogotá's reported traffic fatalities are located on corridors identified as critical, although they only represent 12% of the length of the city's arterial network (and 0.7% of the length of the total road network). Only 4.8% of the vehicles analysed in all critical corridors exceeded the maximum posted speed limit of 60 km/h (5,622 out of 118,332 registered). The corridors selected for speed enforcement registered an average of 10.2% of vehicles speeding over 60 km/h (4,110 out of 40,348 registered) and represent 2.9% of the length of arterial roads.

In addition to the identification of critical segments for speed enforcement, the detailed data generated by the Wi-Fi/Bluetooth devices is also useful to identify the time and day of the week in which enforcement is most needed. Figure 5 shows the percentage of vehicles speeding in the critical corridors by time of day and the number of vehicle samples per hour (each segment is sampled around 300 times per hour). As shown, speeding over 60 km/h is higher between midnight and 5:00 am. At 3:00 am, almost 20% of the vehicles are exceeding 60 km/h. There a lower proportion of traffic speeding on Saturdays and Thursdays than other days (0:00 to 5:00), probably due to specific events during the week analysed (for example precipitation). Mondays have a higher proportion of vehicles speeding than other weekdays, with more than one quarter of the traffic exceeding 60 km/h at 2:00 and 3:00 am (Figure 6).

The data also suggests that speeding is a risk factor in road traffic fatalities. As indicated in Figure 7, there is a higher percentage of fatalities between 0.00 and 5:00 am which coincides with the hours with higher rates of speeding.

Conclusions, recommendations and further research

The case study shows the potential of combining traditional geocoded traffic crash data with detailed speed data obtained from advanced sensor technology. The additional data analysis can inform focused efforts not just in locations where there have been serious traffic collisions, but in places where speeding represents a potential risk. This helps assigning scarce traffic police resources to maximize impact. Strict speed enforcement on the segments selected through the data analysis may result in a 4% decrease in total fatalities annually, which is significant as it corresponds with the annual road safety target for the city. Detailed speed data also display the time, days of the week and segments where speeding is a risk, helping to plan for more efficient enforcement.

The process described here can be further improved. Speed sensors in Bogotá currently detect Wi-Fi/Bluetooth signals to derive traffic speeds without differentiating between the type of vehicle or number of occupants. With some calibration, it may be possible to differentiate between road users. In addition, the detailed speed data was not available in critical segments of urban expressways for the time period analysed. This constraint has now been addressed, as additional detectors have been deployed. Data from fixed detectors could be also combined with GPS data from

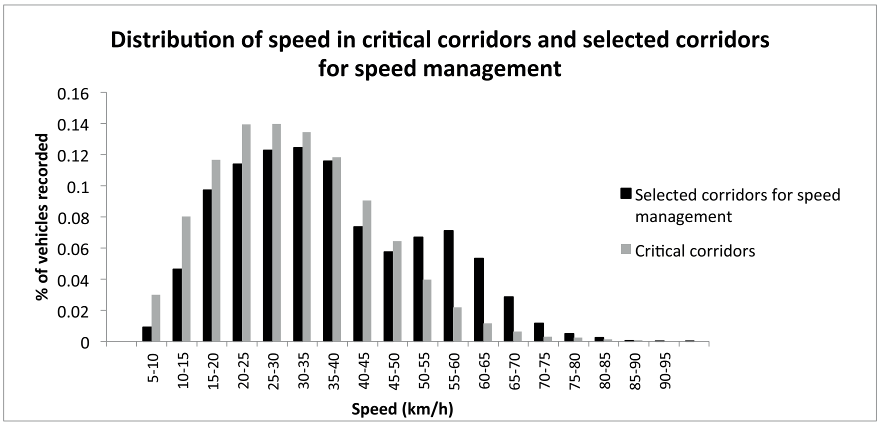

Figure 4. Distribution of vehicle speeds in critical corridors (only corridors in arterial roads with 35 casualties/km/year with speed data) and corridors selected for speed management (critical corridors with more than 5% of vehicles exceeding 60 km/h). Source: Prepared by the Authors based on data provided by Secretaria Distrital de Movilidad, 2017

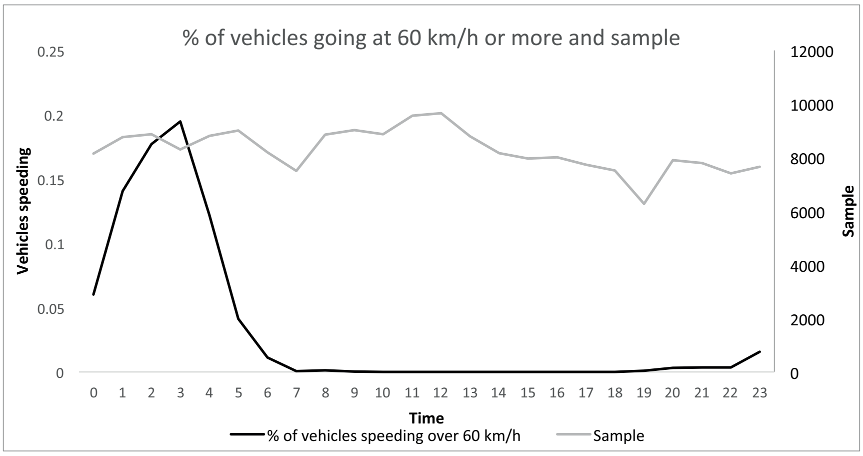

Figure 5. Percentage of Vehicles Speeding over 60 km/h by time of the day (2016) and sample size. Source: Elaborated by the Authors based on data provided by Secretaria Distrital de Movilidad, 2017

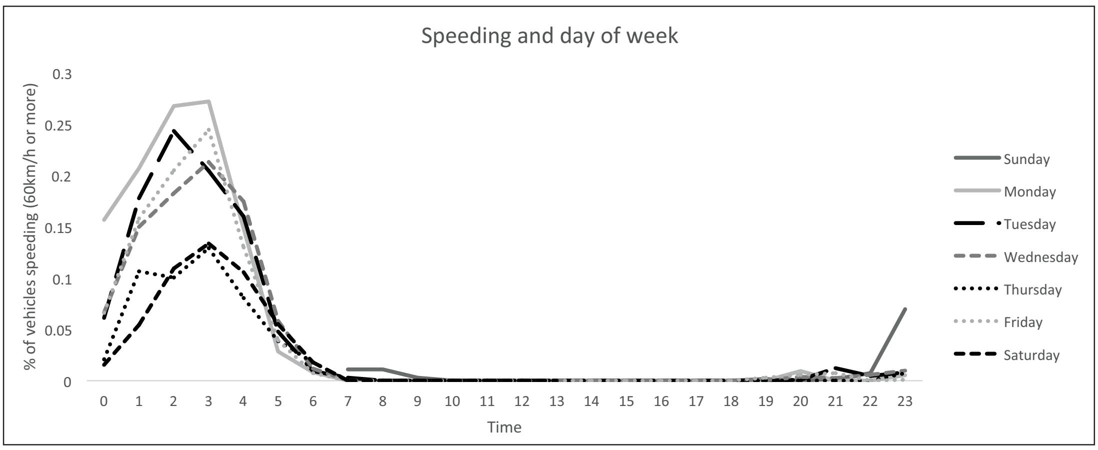

Figure 6. Percentage of Vehicles Speeding over 60 km/h by time and day of the week (2016). Source: Elaborated by the Authors based on data provided by Secretaria Distrital de Movilidad, 2017

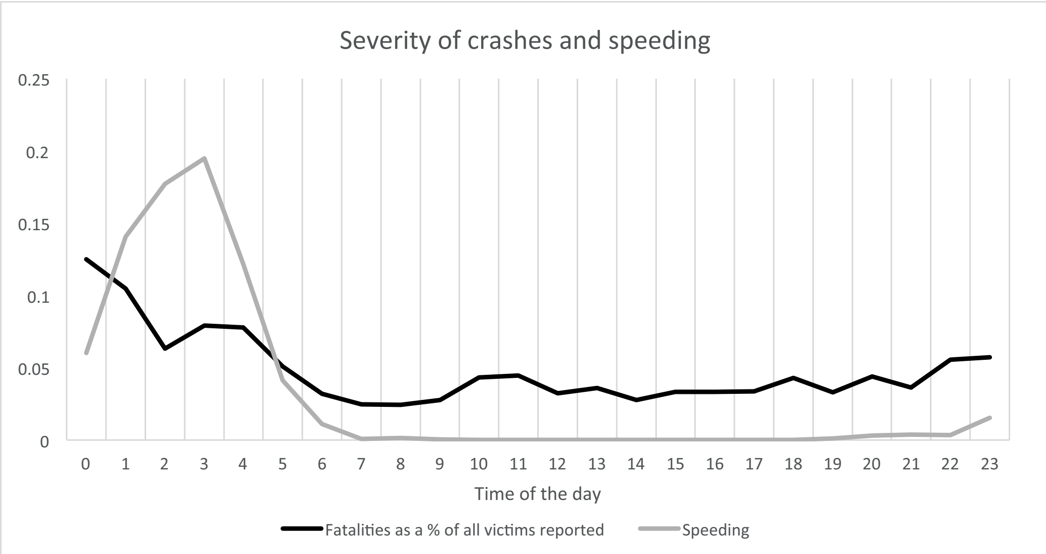

Figure 7. Comparison of percentage of Fatalities (2016) and percentage of Speeding by time of the day. Source: Prepared by the Authors based on data provided by Secretaria Distrital de Movilidad, 2017

vehicles on the road, for instance taxicabs (World Resources Institute, 2017).

The cost of the new traffic control system in Bogotá was USD 10.1 million (Secretaría Distrital de Movilidad, 2015). It includes many other components in addition to the Wi-Fi/ Bluetooth speed detectors. The use of GPS data from vehicle fleets may be more cost effective than Wi-Fi/Bluetooth detectors for cities that have yet not made the investment in dedicated speed detecting devices.

This analysis was conducted using historical traffic crash data (2011-2015), and speed data from a one-week period during September 2016. There is the potential to generate continuous real-time data in the future, which may help in multiple additional analyses.

In this case, the focus was targeting police enforcement, but the analysis presented here could also be used to deploy speed cameras and to introduce physical traffic calming measures, such as rumble strips or narrower lanes, which have proven effective in reducing speeds (Mountain et al., 2005).

In addition to informing strategic speed enforcement, the speed data generated will be very helpful to develop a proactive rather than a reactive approach to road safety, and to conduct a before and after analysis of interventions.

In this case study, speeding was set above 60 km/h, which is the highest posted speed limit in urban arterials in Bogotá. There are segments with lower speed limits, but data on posted speeds was not available at the level of detailed required. Integrating data on posted speeds would make the speeding analysis even more accurate. Data may be also helpful in establishing safe speed limits.

There is a wide potential to integrate big data sources to make informed decisions in urban mobility, establish speed limits and target police enforcement. This pilot application in a developing city illustrates a replicable methodology and it also shows opportunities to further improve the impact of road safety interventions.

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References

Alcaldía Mayor de Bogotá (2016) *Plan Distrital de Desarrollo 2016-2020 "Bogotá Mejor para Todos", Acuerdo 645 de 2016*. Retrieved from: http://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=73425

Bell, N., & Schuurman, N. (2010). GIS and injury prevention and control: history, challenges, and opportunities. *International journal of environmental research and public health, 7(3*), 1002-1017.

Bogotá Cómo Vamos (2017) *Informe de Calidad de Vida, Bogotá Cómo Vamos*. Retrieved from : http://www.bogotacomovamos.org/documentos/informe-de-calidad-de-vida-de-bogota-2016/

Camara de Comercio & Universidad de los Andes. (2017). *Observatorio de Movilidad: Balance de movilidad 2007-2016*. Retrieved from: http://bibliotecadigital.ccb.org.co/handle/11520/19561

Congreso de la República de Colombia. (2002). *LEY 769 DE 2002 por la cual se expide el Código Nacional de Tránsito Terrestre y se dictan otras disposiciones.* Retrieved from: http://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=5557

Doecke, S, Kloeden, C.N. (2011) The accuracy of determining speeding directly from mass crash data and using the NSW Centre for Road Safety method. *Australasian College of Road Safety Conference – "A Safe System: The Road Safety Discussion" Adelaide*. Retrieved from: http://acrs.org.au/wp-content/uploads/27_Doecke_PR.pdf

Global Road Safety Partnership. (2008). Speed management: a road safety manual for decision-makers and practitioners. Retrieved from: http://www.who.int/roadsafety/projects/manuals/speed_manual/en/Greibe, P. (2005). Hastighedens betydning for trafiksikkerheden – danske og udenlandske. Retrieved from: http://asp.vejtid.dk/Artikler/2005/09%5C4422.pdf

Job, RFS & Sakashita, S. (2016). Management of speed: The low-cost, rapidly implementable effective road safety action to deliver the 2020 road safety targets. *Journal of the Australasian College of Road Safety, 27(2)*, 65-70.

Mountain, L. J., Hirst, W. M., & Maher, M. J. (2005). Are speed enforcement cameras more effective than other speed management measures? The impact of speed management schemes on 30mph roads. *Accident Analysis & Prevention, 37(4),* 742-754.

Organization for Economic Cooperation and Development (2006). *Speed Management*. Retrieved from: https://www.itf-oecd.org/sites/default/files/docs/06speed.pdf

Rosén, E., & Sander, U. (2009). Pedestrian fatality risk as a function of car impact speed. *Accident Analysis & Prevention, 41(3)*, 536-542.

Secretaria de Movilidad (2015). *Sistema inteligente de transporte, aporte de movilidad a la transformación de Bogotá en una Smart City*. Retrieved from: http://www.movilidadbogota.gov.co/web/sistema_inteligente_de_transporte_aporte_de_movilidad_a_la_transformacin_de_bogot_en_una_smart_city

Secretaria de Movilidad (2017) *Geolocated Crash Database 2011-2015 and Speed Data from WiFi-Bluetooth detectors for September 2016*. Secretaria Distrital de Movilidad, Bogotá

Semanjski, I, Bellens, R, Sidharta Gautama, J. & Witlox F., 2016. Integrating Big Data into a Sustainable Mobility. *Policy 2.0 Planning Support System, Sustainability 2016, 8(11),* 1142; doi:10.3390/su8111142

Shi, Q., & Abdel-Aty, M. (2015). Big data applications in real-time traffic operation and safety monitoring and improvement on urban expressways. *Transportation Research Part C: Emerging Technologies, 58*, 380-394.

Sisiopiku, V., & Patel, H. (1999*). Study of the impact of police enforcement on motorists' speeds*. Transportation Research Record: Journal of the Transportation Research Board, (1693), 31-36.

Staton C, Vissoci J, Gong E, Toomey N, Wafula R, Abdelgadir J, et al. (2016) . Road Traffic Injury Prevention Initiatives: A Systematic Review and Metasummary of Effectiveness in Low and Middle Income Countries. *PLoS ONE 11(1): e0144971*. https://doi.org/10.1371/journal.pone.0144971

Wilson C, Willis C, Hendrikz JK, Le Brocque R, Bellamy N. (2010). *Speed cameras for the prevention of road traffic injuries and deaths*. Cochrane Database of Systematic Reviews 2010, Issue 11. Art. No.: CD004607. DOI: 10.1002/14651858.CD004607.pub4.

World Health Organization. (2015). *Global status report on road safety 2015*. Retrieved from http://www.who.int/violence_injury_prevention/road_safety_status/2015/en/

World Resources Institute (2017). *WRI Ross Center for Sustainable Cities Joins Partnership to Open Traffic Data and Help Cities Improve Decision Making for Better Mobility*. Retrieved from: http://www.wri.org/news/2017/01/release-wri-ross-center-sustainable-cities-joins-partnership-open-traffic-data-and-help